THE FIRST YEAR OF SCIENCE

HESSLER

REVISED EDITION

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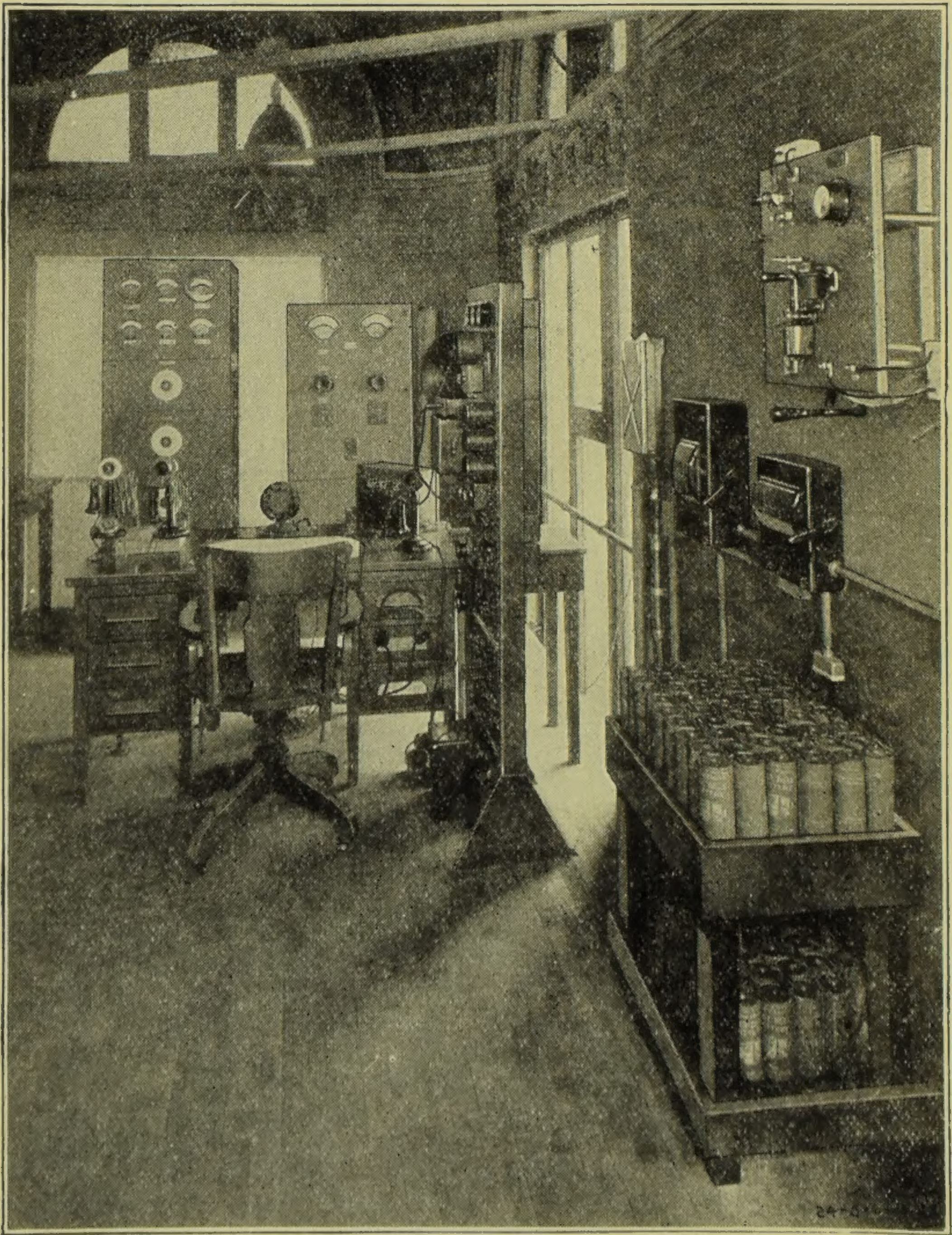

Courtesy of the Sears-Roebuck Agricultural Foundation.

The operating room of a radio-broadcasting station.

THE FIRST YEAR OF SCIENCE

BY

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OF "JUNIOR SCIENCE" AND CO-AUTHOR OF
"ESSENTIALS OF CHEMISTRY"

REVISED EDITION

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PREFACE

The years that have passed since the publication of The First Year of Science have been momentous ones for our educational, as well as our national life. Our educational theory, organization, and practice have been challenged by the needs of a new era. Of no part of the educational system has this been more true than of secondary schools and their courses in science. We are accustomed to say that science is the foundation of modern civilization; yet the fundamental sciences, physics and chemistry, have hitherto been offered only in the upper years of the four-year high school, and, therefore, to only a small proportion of the young people who, at one time or another, are a part of our public-school system. It is self-evident that some knowledge of the physical sciences named is essential for a proper study of biology, physiology, physiography, agriculture, and home economics; little argument should be required to prove that a similar need for these sciences exists in the problems of home-making and our common citizenship. It is, moreover, idle to contend that young people of secondary-school age are not interested in physical science. The civilization into which they are born is teeming with physical equipment prepared for their use. The question is: Shall young people use these tools and machines empirically, without a knowledge of the fundamentals upon which their construction and use depend, or shall the youthful citizen have the intellectual advantage of looking in a scientific way at these devices, of understanding them in principle as well as in use, and of appraising them at their true value? The conclusion is that the physical sciences should be offered, in some form, not later than in the first year of the four-year high school.

The revised edition of The First Year of Science maintains the scientific point of view of the earlier edition and its stress upon fundamental principles. At the same time, every effort has been made to present these principles in readily comprehensible form. The book has been entirely rewritten. In the process its material has been reorganized and at the same time enriched. Much new material has been added. Motion pictures, the phonograph, radio communication, the airplane, and the automobile, as well as many other modern devices, receive merited attention. A chapter on the heavenly bodies has been added. The sections on soil have been enlarged and modernized. A new chapter, Our Food, aims to include the most authentic viewpoints obtainable regarding the necessary food elements and the proper diet for children of school age. The chapters on physiology have been revised with the kind assistance of Miss Erma Smith, of the Department of Physiology of the University of Chicago. The greater number of the illustrations have been redrawn, or are new.

Every effort has been put forth to produce a teachable book. To this end the system of cross references used in the first edition has been maintained. Summaries appear at the close of each chapter. Exercises are placed not only at the end of each chapter, but in several cases in the body of the chapter; while thought-provoking questions are placed in the text itself. Difficult words are pronounced when they are introduced into the text, and appear again in the glossary. A list of reference books is placed at the end of every chapter; these lists are gathered into a book list at the end of the book. An innovation in the revised edition is a list of projects at the end of every chapter. It is not intended that any pupil shall undertake more than one project, or at the most, two, out of any such list. The projects may be assigned by the teacher, or chosen by the pupils, when the study of a chapter is begun, or even longer in advance, in the case of those that require extended observations. The projects may form the basis of short reports to be given in class, orally or in written form, or they may be incorporated in written themes, in correlation with the work in English. Some projects suggest debates upon mooted questions.

In the preparation of the revision the author has been greatly assisted by his wife, Maud C. Hessler, who prepared the material for the chapter on food, and by his daughter, Miss Margaret C. Hessler, of Teachers College, Columbia University. He also acknowledges special indebtedness to Dr. Mary Swartz Rose, Professor of Nutrition, Teachers College, Columbia University, and to the Macmillan Company, for the use of extracts from the tables of dietary calculations given in Dr. Rose's text on Feeding the Family. Most of the new drawings for the revised edition were made by Mr. Robert W. Lahr. The use of the portraits of Faraday, Harvey, and Lavoisier was kindly permitted by the McIntosh Stereopticon Company, those of Galileo and Newton by the Yerkes Observatory, and of some others by Underwood and Underwood. To those who have assisted in the work of the revision, and to the departments of the United States Government, the firms, and the individuals that have assisted him with material and illustrations, the author desires to express his obligation and gratitude.

J. C. H.

CHICAGO, JUNE 3, 1925.

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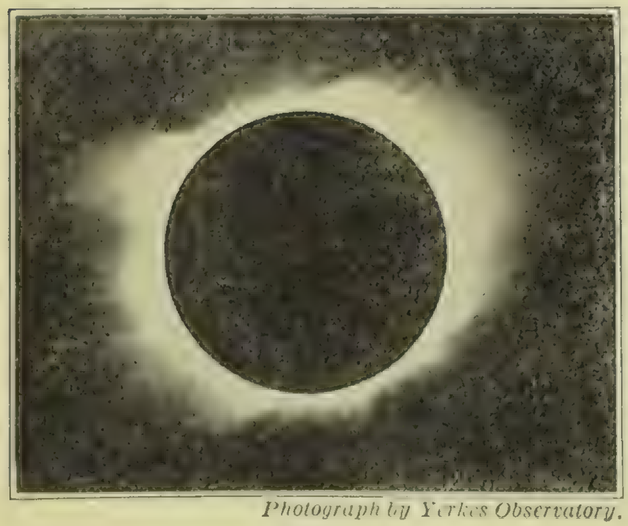
THE FIRST YEAR OF SCIENCE

CHAPTER I

THE MEANING OF SCIENCE

1. What is Science?— If **you** were asked to tell some one what *Science* is, what would you say? Different people would give different definitions. Some would think of that branch of knowledge that has to do with the nature of food plants, and has produced such things as seedless oranges and thornless cacti; some would think of that branch which has to do with the insects that trouble the farmer, and how to get rid of them. Others would think of the science of the rocks, and how we can tell whether or not they contain coal, or copper, or water, or petroleum; others still would think of the ways in which electric currents are produced, or how light acts upon a kodak film, or how iron is obtained from its ores, or how wireless messages are carried. If we sum up all these ideas of what science is, how will the following do for a definition: **Science is the study of the objects of Nature and of what happens to them.** The objects of Nature may be animals, or plants, or rocks, or stars, or a specimen of soda in a laboratory; what happens to them may be growth, or motion, or decay, or use. Thus the rapid growth of a mushroom over night, the rotation of the earth, the crumbling of a granite boulder, the giving off of light by an electric bulb, the dissolving of sugar in water, the souring of milk — all are happenings, or changes, that are studied in science. That which happens to an object may be called a **phenomenon** (plural: phenomena); hence science may also be defined as the study of Nature's objects and phenomena.

We must not imagine that men of former days did not study the objects and phenomena around them; yet some of their conclusions seem very strange to us. In the Middle Ages men were best satisfied with the idea of a flat earth surrounded by water and ice. They invented all sorts of theories as to what holds the earth up. But since Columbus and Magellan, by their famous voyages, demonstrated in a practical way the roundness of the earth, we have become accustomed to the idea that we are living on a great, spherical ball; we see that what we call "down" means **toward** the earth's center, while "up" means **away from** it; we are not afraid that we may fall off the earth some day, or become dizzy from standing heads down.



Photograph by Yerkes Observatory.

FIG 1.

Total eclipse of the sun.

It is not strange that so unusual an event as the **eclipse**, or "swooning," of the sun alarmed men, and that they "explained" the phenomenon by saying that a great beast, or bird, or spirit, covered the face of the sun and cut off its light. Afterwards, however, men observed that an eclipse of the sun never occurs except at the time of "new moon," when the moon is almost exactly between the earth and the sun. Once in so often the moon does come **exactly** between them; then we have an eclipse of the sun. See Fig. 1.

2. What is an Experiment?— Successful discoverers like Columbus and Franklin, Faraday and Edison, were able to do great things for the world because they learned to take notice of common things and to think clearly about them. If we wish really to know ourselves and our surroundings, we must do the same. We must look at the objects and changes about us not only with sharp eyes, but with keen minds. We must ask the "why" of things, and must have the patience and perseverance to work out a sensible answer. Not only such striking phenomena as eclipses, lightning, and earthquakes are worthy of our study, but more common, everyday ones, like the action of soap in washing, the effect of baking powder in

FIG. 2, *a*.
A bullock cart in the Philippines; an example of primitive transportation.

baking, the conditions under which bread grows moldy, or grape juice ferments, how a "cold frame" works, why some soils are sour and some sweet, why a telegraph wire sags on a hot, summer day, and why some plants, such as Indian pipes and mushrooms, are white.

Courtesy of the Chicago, Milwaukee & St. Paul Railway.

FIG. 2, *b*.

The "Olympian" Transcontinental train, operated by electric power, in the Cascade Mountains.

To get the answers to his questions the scientist must not only observe what happens in Nature, but he must carry out **experiments.** That is, he must put a body of material, or an animal, or a plant, under definite **conditions,** so that he may know just what is acting upon it and producing certain results. Thus, the scientist puts a plant in a dark room, so as to learn how it will grow without light; or he feeds different foods to a calf, in order to find out what will make it grow most rapidly; or he puts different sprays upon cherry trees, so as to learn which will cause the trees to produce the best cherries; or he finds what weight may be put upon a pasteboard box before it is crushed; or how much he can stretch a copper wire before it breaks; or what happens to light that is passed through a thick, curved glass, or *lens*. The experiments with the plant, the calf, the trees, the box, the copper wire, and the glass lens are really **questions asked of Nature.** The result of the experiment is the **answer** Nature gives to our question.

3. Science and the Modern World.— In what respect does modern life differ most from that of the past? Is it not in home comforts and conveniences? The ancients and the people of the Middle Ages built finer monuments, tombs, and temples than we are building; but the homes of those times were cheerless and miserable indeed when compared with those of American cities today. Only a few centuries ago even the wealthy could not have the commonest of our modern conveniences. Their houses were full of drafts, and were dark and dirty; medical aid was of the crudest sort; news came slowly; books were scarce and expensive; travelling was hard and dangerous. Farming was very difficult, too; for farm tools were poor and farm machinery unknown.

Even in the days of our great-grandparents such common things as glass and soap were expensive and hard to obtain; houses had no running water; heat and light were not easy to provide; cloth had to be woven at home; and the transportation of fuel, food, people, and news from one place to another was a slow, laborious process. It is only when we compare this condition of things with our own rapid means of transportation and communication (Figs. 2, *a*, and 2, *b*), with our cheap light and books, with our rapid news service, with public libraries, with scientific agriculture, and with modern medicine and its widespread care of the public health, that we realize what science means to us.

As we think of it, we shall also realize that merely to **study** the ways in which science helps us is not enough; we must **apply** science to our way of living. We must not only **know** what will bring us health and power, and what will make us weak and useless; but we must **act** according to this new knowledge. Science shows us how to have sound minds in sound bodies; it is for us to say whether or not we will use it to make our lives worth while.

4. Summary.— **Science** is the study of the objects of Nature and of what happens to them.

Phenomena are the changes in, or what happens to, objects.

To **experiment** is to question Nature with a purpose.

The **chief differences** between the life of men in the past and our life today are due to science.

We need to **use** science as well as to study it, in order to have strong minds in strong bodies.

5. Exercises.— 1. What are the proofs that the earth is round, and not flat? Who was the first to sail around it? When?

2. What is the diameter of the earth? Of the moon? Of the sun? Consult Chapter X.

3. How did Franklin prove that lightning is a great electric spark? When? See Chapter XI.

6. Projects.— 1. Make a list of the great inventions since 1800, with the dates and the names of the inventors.

2. Make a list of the most important tools and machines used by an up-to-date blacksmith, carpenter, and mason.

3. Make a list of the most important tools and machines used by an up-to-date farmer.

4. Make a list of the tools and apparatus used in your kitchen and laundry for baking, cooking, and cleaning.

5. Make a list of the different substances used in your kitchen and laundry.

6. Make a list of the materials used in the building of a brick house.

7. Make a list of the different ways of heating and lighting houses (including public buildings) in your community.

8. Make a list of the different methods used in carrying and lifting passengers and freight, and in distributing news.

9. Make a survey of your block, to find out how many newspapers and magazines are taken by the people living in the block. If you live in the country, make a similar survey of the families in your community.

10. Make a survey to find out the number of books owned by the people of your block or community.

11. Prepare a report on the school library, the books and magazines it contains, and the books useful in your science course.

12. Visit the nearest public library, and report upon the books and magazines it contains, including those useful in your course in first-year science.

References.— BAKER: *Boy's Book of Inventions.* BURNS: *The Story of Great Inventions.* CRESSEY: *Discoveries and Inventions of the Twentieth Century.* DOUBLEDAY: *Stories of Inventors.*

CHAPTER II

AIR AND HOW WE USE IT

7. What is Air?— In our course in science we shall study a great many things about this earth of ours: its water and rocks, animals and plants. We shall also study the conveniences and machines that man has made, and the way in which these inventions have made work easier and living better. Let us first study the gas which surrounds us on every side: the **air**.

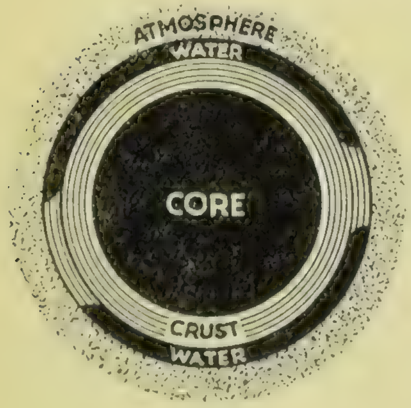


FIG. 3.
An ideal section through the earth. The crust and the water and air layers are much exaggerated in thickness.

What do you know about air? Is air a substance, like water or iron? For what do we use it? Name some machines that are driven by air or "work" because of air. Can we see air?

As you already know, our earth is a great globe (Fig. 3) with a diameter of about 7,900 miles. Filling its great hollows is a layer of water, called the ocean, or the sea, and there are a great many rivers and lakes. If the water of the earth were spread evenly over the land, all the land would be covered to a depth of about two miles. While we commonly think of the word "ocean" as meaning an ocean of water, we must also realize that our earth is surrounded by an ocean of air, which we call the **atmos-**

phere. At the bottom of this ocean we and all other creatures live. Even the best flying bird and the most skillfully made airplane and balloon cannot rise to the top of this ocean, for it is probably 200 miles deep. What is the height of the highest mountain? What is the greatest height ever reached by man in an airplane or balloon?

What is air like? You hear the wind blow, and you know that the air about you is moving. You see the trees swaying in the wind, but not the wind itself. Sometimes you see a quivering motion of the air over a hot stove, or over a hot field or road in summer; but generally the air is invisible.

When you dip some water out of a tub, you can see that the surrounding water rushes into the space from which the water was taken. Do you suppose that if some of the invisible air is removed, the surrounding air rushes into the empty space just as the water does? Men had to get used to this idea before they could learn much about air.

8. Does Air Take Up Room?— Think of a number of objects made of wood, stone, or metal; are they *alike* in any respects?

Of course they are unlike in size, color, and shape; yet there are some ways in which they are all alike. Do not all of them **occupy space,** or take up room? You cannot think of a solid or liquid object that does not. Does air take up room?

When you fill a glass with water from a faucet, does anything flow out of the glass as the water flows in? Try pouring water out of a small-mouth

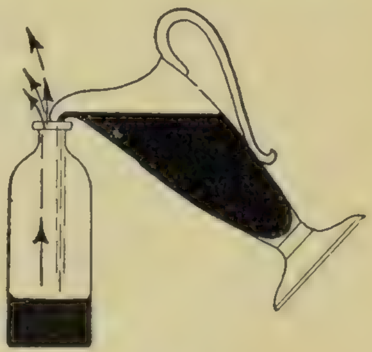


FIG. 4.
As water is poured into the bottle, air flows out.

bottle. Does the water flow out in a steady stream? Try pouring water from a pitcher into such a bottle (Fig. 4); what evidence do you have that air flows out of the bottle as water flows in? Name some common utensils and machines in which we make use of the fact that air takes up room. How about the ink supply bottle of the schoolroom? Why has it two openings?

9. Does Air Have Weight?— How would you get the weight of a cupful of sugar? One way would be to get the weight (Figs. 5 and 6) of the empty cup, then to fill the cup with sugar, and to weigh the cup and sugar together. By subtracting the first weight from the second weight you would obtain the weight of the sugar itself:

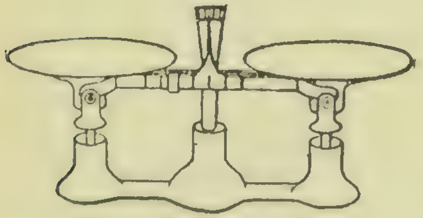


FIG. 5.
Scales for weighing ordinary objects and materials in the laboratory.

Weight of cup+sugar= . . . . ounces (or grams).
Weight of cup alone= . . . . ounces (or grams).
Therefore the weight of the sugar= . . . . ounces (or grams).

How is the weight of the butter in a crock of butter obtained?

In weighing a cup or crock by itself we think of it as *empty;* but is it really empty? Of course it is *full of air.* If we wish to get the weight of the air in a vessel, we must first get all the air out of the vessel, so that it may be really empty.

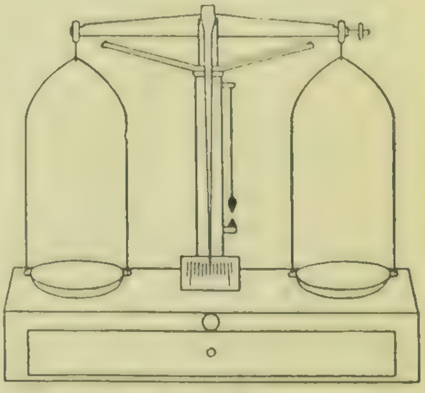


FIG. 6.
Chemical balances, used for weighing smaller objects or quantities of materials.

A convenient form of vessel to use in finding out whether air has weight, and what is the weight of a given volume, is a flask with a narrow neck (Fig. 7). If we attach such a flask to an air pump (see Fig. 11), and set the pump in action, we can get practically all the air out of the flask. If then, while the flask is still attached to the pump, we close the stopper, the outer air cannot get in. We are now ready to weigh the **empty** flask. To fill the flask with air we have only to open the stopper, and the air will rush in. We then weigh the flask and air together, and subtract from this weight the weight of the empty flask. We thus obtain the weight of the air that fills the flask.

By methods like the one just described, it has been found that a cubic foot of air ordinarily weighs about **1¼** ounces. Using the metric system, we say that one **liter** (lēt′ẽr; a little over a quart) weighs about **1.2** grams. A nickel five-cent piece weighs 5 grams, so it takes about 4 liters (practically a gallon) of air to weigh as much as a nickel.

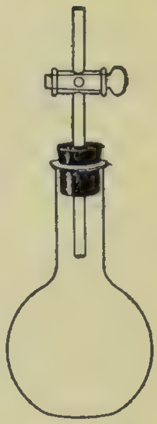


FIG. 7. A flask from which we can remove the air by means of an air pump.

What do we call all those things, taken together, which take up room and have weight? We call them bodies of **matter,** do we not? So air is matter, just as solids and liquids are. Other gases, such as natural gas and fuel gas, are matter, too.

10. How Does a Tire Pump Work?— What is a pneumatic tire? Why do the bicycle and automobile have such tires? How does the tire pump work?

If you examine a pneumatic tire, you will find a **valve** past which the air must be forced **into** the tire. This valve opens inwards. When the tire pump is taken away, the air inside the tire forces the valve **outwards,** and closes it, so that the imprisoned air cannot escape.

A compression pump, such as is used for a bicycle or automobile tire (see Fig. 8), must have at least an **intake** valve. This may be in the piston or in the side of the cylinder; it must open inwards when the piston is raised. The outer air then rushes into the cylinder. When we force the piston down, we compress the air under it. This pressure closes the intake valve, but it opens the valve into the tire. As a result some of the compressed air in the cylinder is forced into the tire. When we raise the piston once more, the movements of the valves are repeated.

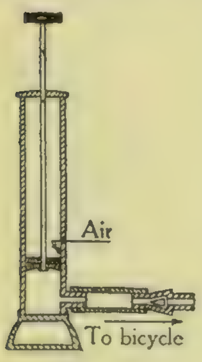


FIG. 8.
At the downward stroke of the piston, air is forced into the tire.

What is the source of the compressed air furnished by a garage for use in inflating automobile tires? The air is either stored in strong tanks, or the garage has a compression pump operated by machinery. Compressed air has a great many important uses. What is used to fill a football or basketball?

11. Other Uses of Compressed Air.— The uses of compressed air depend upon **two facts.** The **first** is that air is very *compressible*, so that a great deal of it can be forced into a small space. This is not true of water, which can be compressed only very slightly even by enormous pressures. The **second** fact about air is that it is *elastic*, as a result of which the compressed air may be carried to other places, and will expand again with great force when the pressure upon it is removed. Hence compressed air may be used to do work.

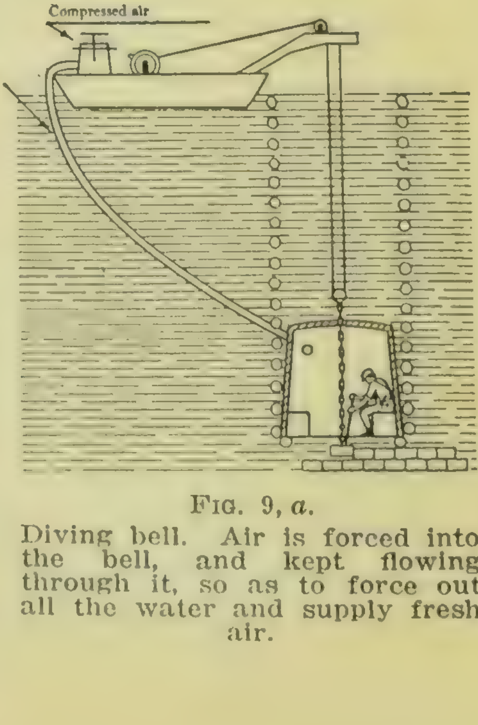


FIG. 9, *a*.
Diving bell. Air is forced into the bell, and kept flowing through it, so as to force out all the water and supply fresh air.

One of the very important

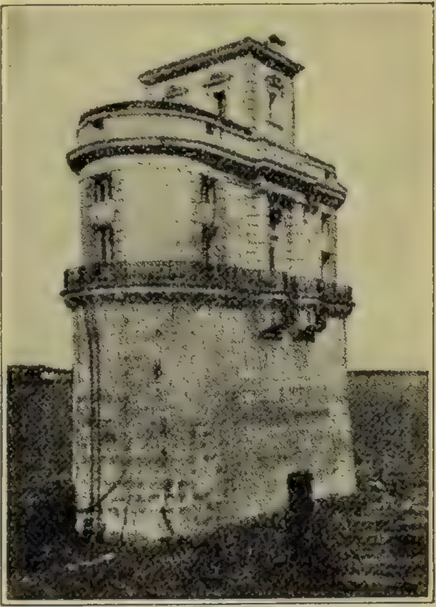


FIG. 9, *b*.
The East Intake Tower of the St. Louis Water System (see § 90), built up from the bottom of the Mississippi River by the use of diving bells or caissons.

uses of compressed air is to *push water out of the way*, so that men can lay the foundations of bridges, lighthouses, and buildings under water (Figs. 9, *a*, and 9, *b*). If you put a drinking glass, mouth downward, under water, the pressure of the water will compress the air in the glass, and force a little water up into the glass. This is what would happen in a **diving bell.** But if compressed air is forced into the bell, it will keep **all** the water out, and will also furnish fresh air for the worker. The foundations for many of our large city buildings must be laid deep, and when the holes are dug, water runs into them. A diving bell used to keep water out of the foundation holes is called a **caisson.** What is the source of such water?

What is the principle upon which a **submarine** boat works (see Fig. 10)? It is that the boat can be raised or lowered in the water according as air, or water, is allowed to fill certain of its compartments. If the commander wishes the boat to rise, he orders the compressed air to be forced into the compartments; the air pushes the water out, and the boat as a whole becomes lighter than water, and rises (§ 121). If he wishes the boat to be submerged, he allows some of the compressed air to escape. Water then rushes into the compartments, and the boat becomes heavier and sinks below the surface.

Compressed air is used to run drills for cutting holes rapidly in steel, and for working **pneumatic hammers,** which can rivet together with great rapidity, the pieces of steel of a large building or bridge. Have you heard the rushing noise made as the **brakes** of a trolley car are released, just before the car is started? The sound was probably due to the escape of the compressed air which had been used to "set" the brakes when the car was stopped. How is the compressed air on a trolley car obtained? Ask the motorman to tell you. The air brake was invented by **George Westinghouse.** Find out something about him.

Courtesy of the U. S. Navy Department.

FIG. 10.
A bow view of an American submarine.

A blast of compressed air is used in blowing away the sand and dirt left upon a casting; also to drive sand with great speed against glass and make it roughen the surface of glass, producing "ground" glass. What would be the effect of the sand blast, if the glass were all covered with wax except some design that was left uncovered?

12. Exercises. 1. Why is there a vent, or small hole, near the top of a vinegar or kerosene barrel? Why is there one in a steam radiator?

2. How does the liquid come out of the spout of a kerosene or gasoline can when the top is closed? When it is open? Why?

3. Find the number of cubic feet of air in a room 20 feet long, 15 feet wide, and 9 feet high. How much, in ounces, does the air weigh? See § 9. How much in pounds? How much in grams?

4. If you bring an inflated toy balloon from the cold, outside air into a warm room, what will happen to it? Why?

5. If no air gets into, or out of, a filled automobile tire, when will the pressure in the tire be greater, on a cold day or on a hot day? Why?

6. Suppose that the inside volume of a football is $\frac{1}{5}$ of a cubic foot. What does this volume of air weigh? Will the air in the ball weigh more, or less, than this when the ball is inflated for play? Why?

7. Why does the smoke from a stove go up the chimney?

8. Give an accurate explanation of the working of an ordinary toy popgun.

13. Has the Atmosphere a Pressure? — In § 7 we learned that we live at the bottom of an ocean of air. If we were living at the bottom of an ocean of water, there would be a great pressure upon our bodies and upon all other objects, because of the weight of the water above us. Is there such a pressure due to the weight of the atmosphere?

(a) Blow a paper bag full of air. Since the bag is open to the air, the pressure inside and outside the bag must be the same. Now make the mouth of the bag small and remove the air by suction. Why does the bag collapse? Would a tin can collapse if you removed the air from it? Why does not the flask shown in § 9, Fig. 7, collapse as readily as the paper bag?

(b) If the school has an air pump, carry out the experiment shown in Fig. 11. If the rubber sheet is not strong enough, it may be broken by the air trying to get into the space under the rubber. Why does not this happen when there is air under the rubber?

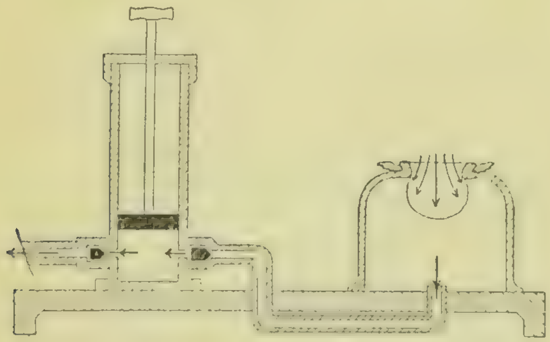


FIG. 11.
As the air pump is worked, it removes air from the bell jar covered with sheet rubber (on the right). The pressure of the outer air stretches the rubber, so that it bulges inward.

(c) Fasten a piece of sheet rubber tightly over the mouth of a clay pipe, and remove some of the air inside by suction through the stem. Explain what happens. Does it make any difference whether the bowl of the pipe is held upright, or sidewise, or upside down?

(d) Hold a small-mouth bottle between your lips and remove as much air as possible by suction. Then, before the air rushes into the bottle, close the bottle's mouth with your tongue or the inside of your lips or cheek. What causes the bottle to "stick" to you? What happens when you pull the bottle away? Explain it.

(e) Fill a tall bottle or jar entirely with water, cover the mouth of the vessel tightly with the hand, and set the vessel upside down, in a pan of water. Does the water fall out when you remove your hand? What holds it up?

(f) Fill a water glass or large-mouth bottle completely with water; close the mouth of the vessel tightly with a wet piece of cardboard or stiff paper. Hold the cover in place with your hand while you turn the vessel upside down; then carefully remove your hand. Why does not the water fall out? In what direction does the atmosphere's pressure act in this case?

14. How Does a Lift Pump Work? — Does the pressure of the atmosphere have anything to do with your being able to drink lemonade or soda water through a straw? Suppose that the straw were 5 feet long, do you think you could raise the liquid to that height? If it were 50 feet long? Is there any limit to the height we can lift a liquid in a tube by suction, or does it depend only upon the strength of the suction apparatus?

To answer these questions let us study the construction and working of the simple suction pump, or lift pump, or a glass model of such a pump (Fig. 12). We shall find that the pump consists of a piston that can be moved up and down in a cylinder, or pipe. The lower end of the cylinder dips below the level of the water. The piston has a valve which opens upwards; there is another valve in the cylinder, opening in the same direction.

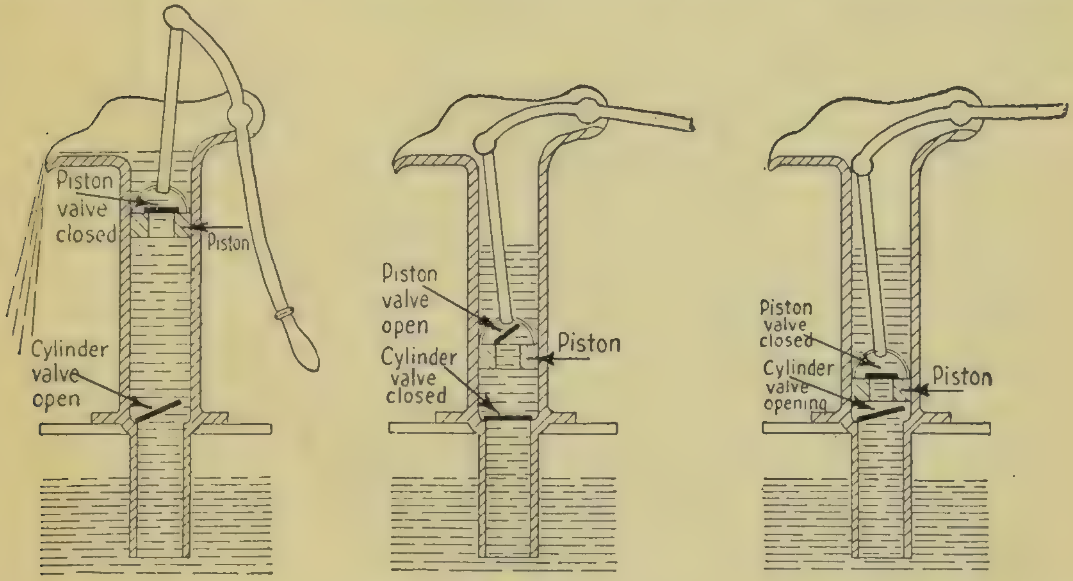


FIG. 12.

A lift pump, with its piston and valves in three positions. In the middle one the piston is near the bottom of the downstroke. In the one on the right the piston is starting upward. In the left position the piston is near the top and water flows out.

When we push the piston downward, the air below it opens the piston valve, and some of the air rushes above the piston. On this downward stroke the cylinder valve remains closed. When we lift the piston, its valve is forced shut by the pressure of the air **above** it, and the cylinder valve is opened upward by the expansion of the air **below** it. When we push the piston downward once more, we remove a second portion of air from the cylinder. After several up and down strokes of the piston, we find that all the air has been removed from the cylinder, and that water rises above the cylinder valve, and finally above the piston valve. The next upward stroke of the piston will lift water to the level of the spout, so that it will flow out; further pumping will lift more water until we get a more or less steady stream.

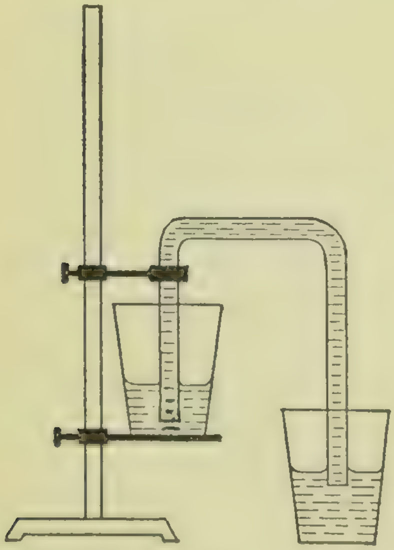


FIG. 13.
A siphon. In which direction is the water flowing? Why?

It has been found that at sea level the top of the water in a well or cistern must not be more than about 34 feet below the lowest position of the piston, or the pump will not work. This statement answers the questions asked at the beginning of this section: there *is* a limit to the height we can raise liquids by suction. The reason for this limit of 34 feet is that the water is raised from the level of the well or cistern to the piston by the *pressure of the atmosphere* upon the water in the well. The atmosphere's pressure can just balance a column of water 34 feet high, but no higher. So we are really depending upon the atmosphere to raise the water from the well, and not upon the suction of the pump. The pump is merely a device for removing the air above the water in the pump.

The **siphon** (Fig. 13) is used for carrying a liquid over the side of a vessel; it works because of atmospheric pressure.

15. What is a Barometer?— If you think of it, you will see that a lift pump, such as we have just studied, is really an air pump, and works like one. We remove the air over the water of a well or cistern, just as we remove the air from a closed flask (see Fig. 7). In the case of the water pump, the pressure of the atmosphere forces water into the pump to take the place of the air we remove. If we place a tube in a dish of mercury (Fig. 14), and remove the air in the tube by means of an air pump, do you think that the atmosphere's pressure will force mercury up into the empty tube? Try this if possible. You will find that the mercury is forced up as the water is. However, even a perfect air pump will not make the mercury rise more than about 2.5 feet, or 30 inches (760 millimeters), above the mercury in the dish. What is the cause of this difference? The answer is that mercury is much heavier, volume for volume, than water. By what number must you multiply 2.5 to get 34? Work the problem. The answer is 13.6, is it not? Well, mercury is 13.6 times as heavy as water, hence the atmosphere's pressure can lift a column of mercury only 2.5 feet high, while it lifts water 34 feet. Gasoline is only about ⅔ as heavy as water; how high can a lift pump raise it?

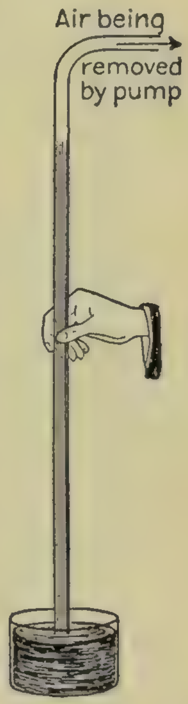


FIG. 14.
As we remove the air inside the tube, the pressure of the atmosphere on the mercury in the dish forces mercury up the tube.

In making an ordinary **barometer** (Fig. 15) you do not need to use an air pump. You can use a tube closed at one end (the tube should be more than 30 inches long), and fill the tube with mercury. Then close the open end of the tube with your thumb, turn the tube upside down, put the open end under the level of some mercury in a dish, and remove your thumb. You will find that the top of the mercury left in the tube is about 30 inches, or 2.5 feet, above the level in the dish. This apparatus is called a **barometer** (bă-rŏm′ē-ter). The level is not always exactly 30 inches, but varies a little from day to day. The length of the mercury column is called the *height* of the barometer. The **standard height** used in science is 760 mm.

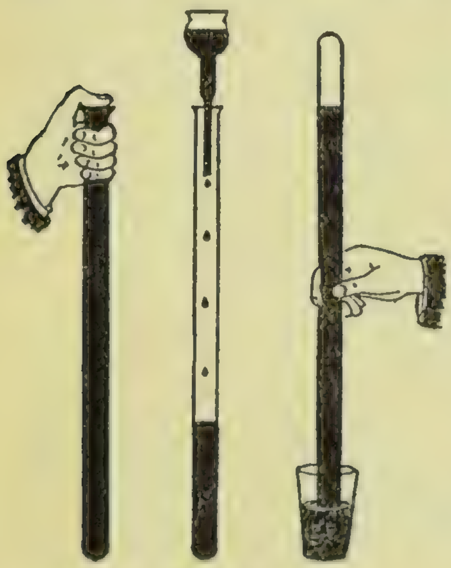
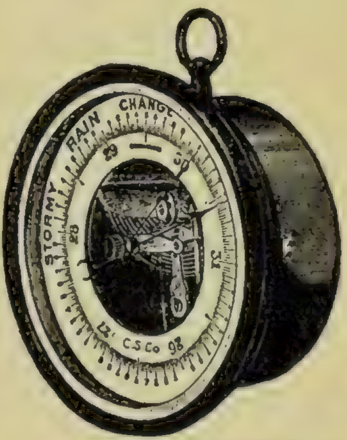


FIG. 15.
Filling a long glass tube with mercury and making a barometer out of it.

We often state the amount of the atmosphere's pressure at the earth's surface as about 15 pounds to a square inch of surface; how do men get this number? If the opening (or cross section) of the barometer tube has an area of one square inch, the mercury column 30 inches high will weigh 14.7 pounds. Does it seem possible that the atmosphere has so great a pressure? What must be the weight of a column of water one square inch in cross section and 34 feet high? Of a column of the atmosphere of the same cross section and extending to the top of the atmosphere?

Aneroid Barometer.— While you have been studying about the barometer, you may have been thinking that the instrument which you have been calling a barometer, and which you have seen in offices and stores, or on shipboard, is not a tall instrument like the mercury barometer at all, but a round object, somewhat like a clock (Fig. 16). Such a barometer is called an **aneroid** (ăn′ĕr-oid) barometer. It really consists of a small metal box from which all air has been removed. The box is fitted with elastic metal sides that bend inward ever so little when the atmosphere's pressure becomes greater, and spring back into place when the extra pressure is released. This slight movement of the sides of the box moves a system of levers and wheels, and causes a comparatively large movement of the "hand" or pointer, on the "face" of the instrument. Of course, the aneroid barometer must first of all be compared with a standard mercury barometer, so that the manufacturer may know to what atmospheric pressure each position of the pointer really corresponds. Which is more convenient to carry about, a mercury barometer, or an aneroid one? Why?



Central Scientific Co.
FIG. 16.
Aneroid barometer.

16. Does the Atmosphere's Pressure Change?— If we keep a careful record of the height of the barometer at different times, we shall find that it varies from day to day and sometimes from hour to hour. These changes in the barometer height are caused by changes in the pressure of the atmosphere. The weather observer uses these changes to help him in foretelling the weather, as we shall see in §§ 141 and 142.

Does the atmosphere weigh the same, volume for volume, at all heights from the earth's surface to the top of the atmosphere? If you were at the bottom of a haystack, trying to work your way up through it, your task would be hardest at the bottom, and would become easier toward the top. The hay is most compact, or dense, in the lowest layers, because these layers have to bear the weight of all the hay above them. Which pillows in a pile are most compressed? So it is with the atmosphere: its lower layers are crowded together by the weight they must hold up.

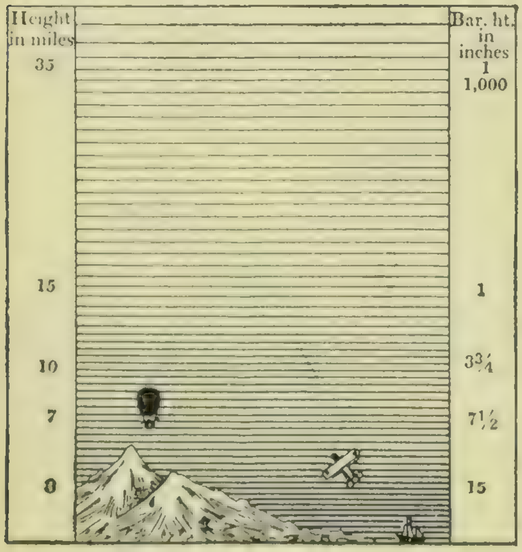


FIG. 17.
The balloon and the airplane are still in the lower part of the atmosphere, although the air above them is much less dense than below them.

Men have found (Fig. 17), by carrying barometers up mountains or in a balloon, that the atmosphere's pressure grows less as they ascend. The barometer column falls about an inch for every 900 feet of ascent above sea level. At a height of about 4 miles above sea level the pressure of the atmosphere can hold up a mercury column only 15 inches high. This means that half of the weight of the atmosphere is within 4 miles of the earth's surface. In a certain balloon ascent the barometer fell to 7 inches when the balloon was 7 miles above sea level. About what portion of the air was below the level of the balloon? An exploring balloon (without passengers) has gone 23 miles above sea level, leaving $\frac{299}{300}$ of the air below it. When a barometer is carried down into a deep mine, the mercury column is higher than at the surface, because the air column is longer, and therefore heavier, than at the mouth of the mine.

17. How We Measure the Air Pressure in a Tire.—

You have seen the pressure gauge used to test the pressure of the air in an automobile tire (Fig. 18). Could a barometer be used for this purpose? Of course it could, if we had a way of attaching the tire air-tight to the barometer. But the barometer would have to be a tall one to measure a pressure of 55 to 65 pounds to the square inch. The tires of large trucks carry 105 pounds to the square inch or even more. Such pressures are needed to keep the tires properly inflated and yet to avoid bursting. The ordinary gauge is a combination of two steel tubes, one of which moves within the other. When the valve in the tire is opened, a little of the air of the tire rushes into the gauge. This air expands a rubber sac, which pushes up the inner tube of the gauge to a certain mark, and thus gives the amount of the air pressure in the gauge and tire. A spring surrounds the rubber sac and prevents it from bursting.

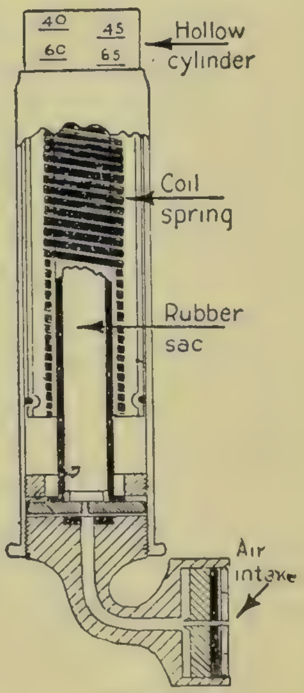


Fig. 18.
An automobile tire-pressure gauge.

18. Summary.— The **atmosphere** is the ocean of air at the bottom of which we live.

Air is matter, for it takes up room and has weight.

Air is elastic, and may be compressed and expanded.

Compressed air can do work when it expands.

The **pressure** of the atmosphere is due to the weight of the air.

A **lift pump** is a device for removing the air over a column of water. Atmospheric pressure raises the water to the piston of the pump.

A **barometer** measures the atmospheric pressure in terms of a mercury column.

The **atmospheric pressure** decreases as we ascend above sea level, and increases as we go below sea level.

19. Exercises.— 1. If the barometer column falls about one inch for every 900 feet we ascend above sea level, what would its height be at an elevation of 1350 feet? Of 2700 feet? Of one mile?

2. The pressure of the blood in our bodies is about 17 pounds to the square inch. Why may it be dangerous for some people to be carried upward too quickly in a balloon or airplane or on a mountain railway? Why do some persons have nosebleed when ascending a mountain?

3. If your body has an area of 2000 square inches, and the atmosphere's pressure is 15 pounds to the square inch, what pressure does your body support? Why do you not feel so great a pressure?

4. When the cover of a Mason fruit jar is hard to remove, we place a knife blade under the edge of the cover until there is a hissing noise. What causes the noise? Why is it easier afterwards to unscrew the cover?

5. If an elastic balloon holding 100 cubic inches of gas at sea level were to ascend to a mountain top, would the volume of the gas in the balloon grow larger or smaller? Why?

6. Why is it so hard to pump water with a dry pump? What is the use of adding a little water, or "priming" the pump?

7. How could a barometer be used to tell the height of a mountain?

20. Projects.— 1. Measure the length, width, and height of your schoolroom, and calculate how many cubic feet of air it contains. Then find the weight of the air in it. Change the weight in ounces into the weight in pounds.

2. Balance two dry, "empty" tomato cans upside down on the two pans of the laboratory scales; then heat one of the cans by means of a burner. Find out if it is lighter, or heavier, than the cold can, and explain the result.

3. In a room with two doors, and all other openings closed, carry out the following experiment: almost close one of the doors, and suddenly close the other door. What is the result? What is the result of suddenly opening one of the doors? Explain both results.

4. Construct a siphon (see Fig. 13, § 14), for carrying water over the side of a vessel. Report to the class what it is that raises the

water to the top of the bend, in which direction the water flows, and why. See a textbook of physics.

5. Write a paper on the uses of siphons.
6. Make a model lift pump and demonstrate its working.
7. Write a paper on the air pump and its inventor, Otto von Guericke.
8. Write a paper on the results of the invention of the air brake.
9. Make a mercury barometer.
10. Write a paper on the invention of the barometer by Torricelli.
11. Carry a barometer from the basement of the highest building in town to the top floor of the building, and report the results.
12. Make a list of the uses of compressed air.
13. Demonstrate the working of a bicycle pump.
14. Demonstrate the working of an automobile tire valve.
15. Open a sealed fruit jar and determine if the air pressure inside is greater or less than that outside. Calculate also how great the air pressure upon its cover is, if the area of the cover is 6 sq. in.
16. Make a determination of the weight of the air in an inflated football or basketball.
17. Demonstrate to the class the working of a trolley-car air brake.

21. References.— BARBER: *First Course in General Science.* MILLIKAN AND GALE: *A First Course in Physics.* SMITH AND JEWETT: *Introduction to the Study of Science.* TALBOT: *Submarines.* TOWER, SMITH, TURTON, AND COPE: *Physics.*

CHAPTER III

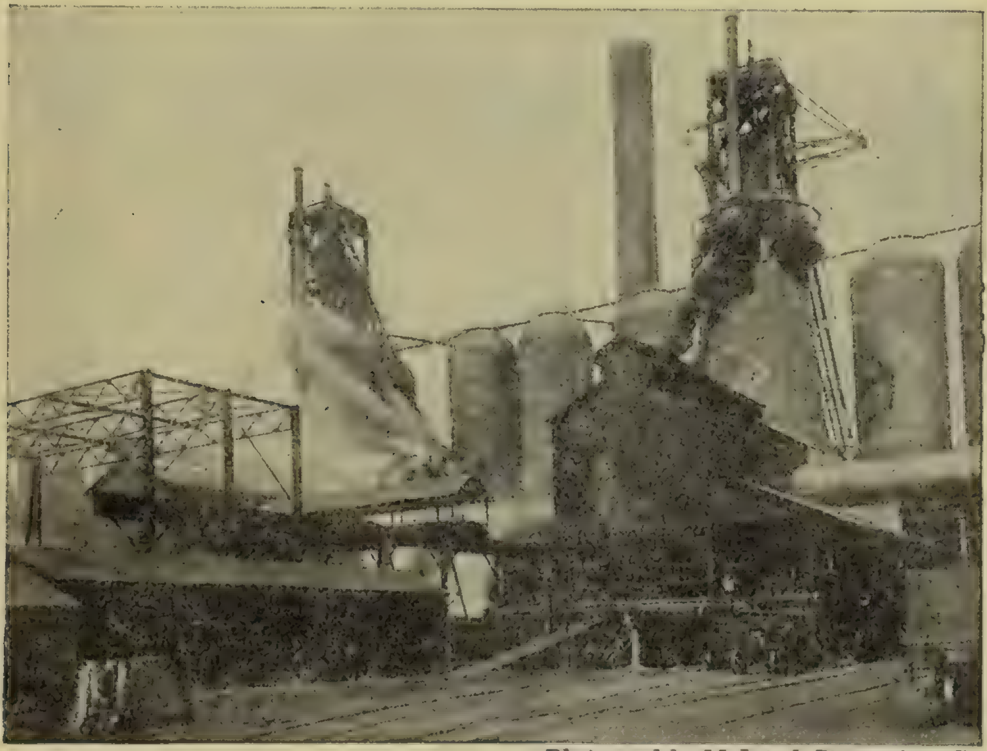
HOW FIRE DEPENDS UPON THE AIR

22. Fires and How They Burn.— What are some of the forms of fire? You think at once of the great accidental fires that burn cities and forests, coal mines and petroleum wells; there are also the small fires of the home, such as a burning match or candle or kerosene lamp, or the fire in a cook stove or furnace. Then there are the great fires of industry: the furnaces in which fire is used to turn large quantities of liquid water into steam for the running of powerful engines; the enormous blast furnaces (see Fig. 19) and smelters in which, by the aid of fire, metals such as iron, lead, copper, and zinc are prepared for human use.

Watch a match burn, and see how the flame creeps along the stick. A city block burns in the same way. Each part that is burning heats the part next to it so hot that it, too, begins to burn. We call this temperature at which a body begins to burn the kindling, or ignition (ĭg-nĭ′shŭn) temperature of that body. Is the ignition temperature of the match head the same as that of the stick? What are the stages in the kindling of a bonfire? A substance which will burn readily in air is called a **combustible** substance. Name some combustible and some incombustible substances.

Most fires burn with flames, but some merely **glow** (see § 25). **Smoke** may be either some of the unburned body in finely divided form, or some of the materials formed in the burning and condensed when they strike the cold air.

23. Experiments with Burning Bodies.— In §§ 7-9 we learned that air is a form of matter, and as such has weight and occupies space. If we use up some of it, there will be less than there was; but how are we to find this out, if the surrounding air rushes in to take the place of that which we remove? You can see that we must work with a confined portion of the air, that is, with a bottle, or tank, or some other vessel of it.



Photograph by McIntosh Stereopticon Co.

FIG. 19.

In a blast furnace iron ore, coal (or coke), and limestone are subjected to great heat to produce pig iron. Slag is a waste product of the action.

Burn a pine splinter in a bottle of air (Fig. 20, *a*). The bottle must have a stopper to which the splinter can be fastened. At first the flame burns brightly; finally it goes out. If we remove the stopper, relight the splinter, and put the splinter once more into the bottle, the splinter will not burn. The air of the bottle has lost the power of supporting the burning of the splinter.

Refill the bottle with fresh air, either by letting it stand for some time or by filling it entirely with water and then pouring out the water. Will the burning splinter now continue to burn? This experiment shows us that after a time burning wood destroys the power of the air to support burning, and that we must supply fresh air in order that burning may go on. The same is true of all ordinary burning.

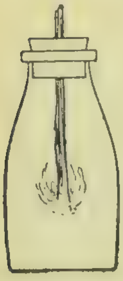


Fig. 20, *a*. A lighted splinter burns for a short time in the air of the bottle and then goes out.

We can also burn a candle (best, a short one) in a closed jar of air, using a stiff wire to hold the candle upright. The candle will burn for a short time, and then go out. Burning sulphur held in a long-handled spoon (combustion spoon) may also be burned in a bottle of air for a time. Then, although there is plenty of sulphur left, burning stops, and there is a gas, with a sharp odor, in the bottle. If a burning splinter or candle is now held in the bottle, it will cease burning.

If will be interesting to find out what happens when we burn a combustible, such as a candle, in a bottle, and use a movable stopper, such as water (Fig. 20, *b*). Of course, the bottle must be upside down. We use a candle long enough so that the wick is near the middle of the bottle. Soften the bottom of the candle by warming it, and press it against a piece of tin, such as a jelly-glass cover, so that it sticks. Light the candle, and set it upright in a basin having water to the depth of about an inch. Put the bottle of air over the burning candle and into the water. While the candle is still burning, water rises into the bottle. Does not this mean that there is less air in the bottle after the candle has burned in it? What has become of this air?

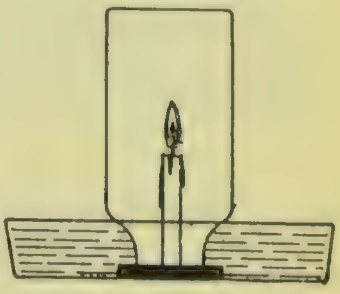


Fig. 20, *b*. The water acts as a movable stopper for the bottle of air. As the candle burns, it uses up some of the air.

24. Does All the Air Support Burning?— We have seen that the pine splinter, the candle, and the sulphur all burn for a while in a closed bottle of air, and then go out. Is this due to the fact that they have used up all the air in the bottle, or is it possible that only part of the air supports burning? None of the substances named can help us so much, in our study of what takes place in burning, as can the substance **phosphorus** (fŏs′-fōr-ŭs). This is a substance which burns with great fierceness; so that all experiments with it must be performed by the teacher, or under careful direction, or serious burns may result.

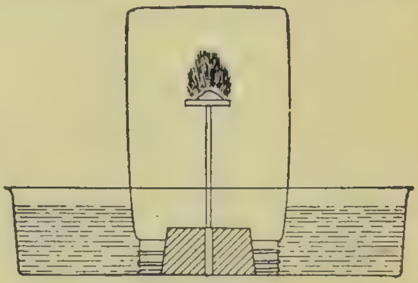


FIG. 21.
The phosphorus burns until it has used up that part of the air which allows burning to take place.

Phosphorus exists in two forms: a red powder and a white or yellowish solid, which comes in sticks. The red form is much safer to use. If the white form is used, it must be kept under water and cut under water, or it may take fire "of itself," or spontaneously. Use forceps, never the fingers, to handle the piece cut off.

Let the teacher set up the apparatus of Fig. 21, using a pint fruit jar and a shallow pan containing water. The phosphorus holder may be a strip of "tin" with a horizontal top about the size of a 25-cent piece, or it may be a small cork fastened to a wire and covered with a piece of tin. The lower end of the strip or wire may be put through a hole or slit in a piece of sheet lead or into a rubber stopper, so that the holder will stand upright. If desired, a floating support for the phosphorus may be made out of a thin, flat cork with a piece of tin laid upon it.

When the support is ready, set the phosphorus on fire, put the jar of air over it, and press the jar against the bottom of the pan, so that no air can escape. The phosphorus will burn, forming a dense, white smoke; then, although not all the phosphorus may be consumed, it will stop burning. Finally the smoke will dissolve in the water, and the gas in the jar will be clear. During the burning, and until the gas is cool, water will rise into the jar.

Close the mouth of the jar by slipping under it a stiff card or a sheet of glass; then remove the jar from the water and set it upright. Put a burning candle or match into the gas; you will find that the gas does not allow burning to go on. Find out what proportion of the air in the jar has disappeared; is it $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or what? When the experiment is performed with great care, the water rises into the jar until it fills about $\frac{1}{5}$ of it (nearly 21 per cent).

Many other substances burn in air until they have used up about $\frac{1}{5}$ of it, and then cannot act further. How can we explain this? The explanation is that what we call "air" is really made up of at least two different gases. One of these permits the burning of combustible substances, while the other does not. The active gas, which disappears in burning, we call **oxygen.** It makes up a little more than $\frac{1}{5}$ of the volume of air. The inactive gas, which burning bodies do not seem able to affect, is **nitrogen** (mixed with a small proportion of other inactive gases, such as *argon*). We can think of the air as oxygen diluted with nitrogen, as lemonade is lemon juice diluted with water.

25. Explanation of Burning and Flame.— What, then, is the strange phenomenon we call fire, or burning? It is the *uniting of the burning body with the oxygen* of the air. When the kindling temperature has been reached, the combustible substance and the oxygen rush together so vigorously that heat and light are produced. What becomes of the burning body? Sometimes it seems to disappear, because the product formed is a colorless gas; sometimes, as in the case of phosphorus, the product is a solid, and we see it as smoke. But in every case, if we are skillful enough, we can collect the invisible materials formed, and show that they contain all of the combustible substance and oxygen besides. Men used fire for ages before they knew what it really is.

Another name for burning is **combustion.** It is from this that we get the word **combustible.**

Why does the **flame** of a bonfire, or a burning house or haystack, reach out so far from the burning body? Why is it that a jet of gas, or a candle, or a piece of soft coal, burns with a flame, while a piece of punk, or coke, or charcoal, merely glows? The answer is that **a flame is a burning gas.** Substances which do not give off gases when they burn, do not have flames. Wood burns with a flame because it gives off much gas when heated, and it is this gas which burns with a flame. When the wood has been changed into **charcoal** (see § 59) by the loss of the materials which could be driven off as gases, the charcoal burns with a **glow.**

Watch the burning of a candle. When you light the wick, a little of it burns up, and in so doing melts some of the wax, and forms a tiny bowl of oil. The oil is drawn by **capillary** (căp′ĭl-ār-y̆) **action** (see § 119) up the wick into the flame. The heat of the burning wick now changes the oil, or melted wax, into a gas, or vapor, and this burns with a flame, giving heat and light. The flame extends out as far as there is gas burning. The gas is constantly being burned up, but more is constantly being formed from the melted wax; hence the flame seems to have a definite shape and size.

If you look at the candle flame carefully, you will see that it consists of a dark, central part surrounding the wick, and a burning, outer part that gives the light. Hold the end of a small tube in the central part, as shown in Fig. 22, *a*. If you bring a burning match near the upper end of the tube, you will get a flame there, too. This shows that there is an invisible, combustible gas in the central part of the flame. Why does not this gas burn in the interior of the flame? The answer is that the air gets at it only on the outside. So the candle flame in reality consists of a burning, outer region surrounding a central region of unburned gas.

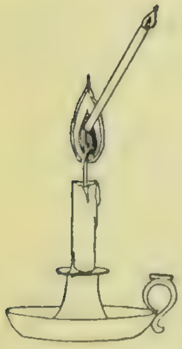


Fig. 22, *a*. The glass tube draws off from the center of the candle flame a combustible gas.

You can show in other ways that a flame is a burning gas. Blow out a candle flame, and at once hold a burning match above the wick. By making a few trials you will find that the match may be held quite a distance above the wick, and yet will relight the candle. If we give the wick time to cool, it can no longer turn the wax into a gas; then we cannot relight the candle unless we heat the wick once more to its kindling temperature (see § 22). You can carry out the same experiment with the wick of a kerosene lamp (Fig. 22, *b*). In this case the liquid kerosene is drawn up by the **capillary action** of the wick (see § 119) into the flame and changed to a gas before burning.

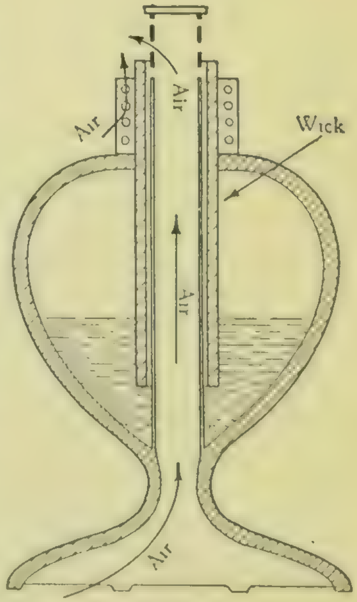


Fig. 22, *b*. In the center-draft kerosene lamp, air reaches the kerosene of the wick from the center as well as the outside of the burner. Consequently the flame is very bright.

26. Discovery of Oxygen.— The phenomenon of fire, or burning, has fascinated men for ages, but what the air has to do with it no one understood until 1774. The explanation was given by **Lavoisier,** a French scientist, and was as important, in its way, as the explanation of gravity by Newton § 108). **Priestley,** an Englishman, had just prepared **oxygen** (Aug. 1, 1774) by heating a red powder which we now call **mercuric oxide.**

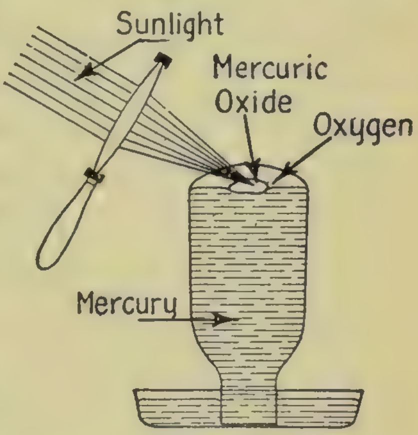


FIG. 23.
How Priestley obtained oxygen from mercuric oxide.

Priestley's apparatus (Fig. 23) was a bottle filled completely with mercury, and inverted in a "bath" of mercury. He put the mercuric oxide under the mouth of the bottle; the oxide, being lighter, floated to the top of the mercury. He then brought sunlight to a **focus** (§ 206) upon the mercuric oxide by means of a burning lens. The heat produced caused the red powder to disappear; but a colorless gas appeared in its place. When Priestley put into the gas a splinter with a glowing tip, the spark burst into flame. He also put a live mouse into the gas, and, to his surprise, it continued to live. Priestley called the gas "good air."

The Air a Mixture.— When Lavoisier heard of Priestley's discovery, he reasoned that the gas obtained by Priestley, which supported burning and life so much better than air, must be present in the air. So he planned an experiment to prove that he was right.

Lavoisier set up the apparatus shown in Fig. 24, putting some mercury in the glass **retort.** The drawn-out tube of the retort was bent so that it dipped into the pan of mercury. Over the end of this

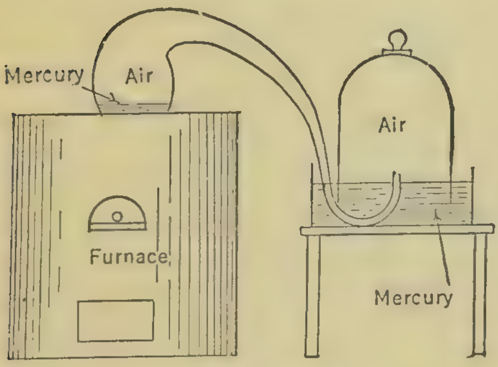


FIG. 24.
Lavoisier's experiment, in which he heated mercury in contact with a confined portion of air.

tube, and dipping below the mercury, was the **bell jar.** The air of the bell jar and of the retort was thus cut off from the outer air, and nothing but mercury could get into the apparatus. Lavoisier then heated the retort for 12 days. Gradually a red powder collected on the mercury in the retort. At the same time the atmospheric pressure pushed some mercury into the bell jar. This showed that the volume of air in the apparatus became smaller. When no further change took place, Lavoisier let the apparatus become cool, and found that only $\frac{4}{5}$ of the air remained. The air that was left "put out" a burning candle, and mice could not live in it. So Lavoisier reasoned that the **active** part of the air was removed by the heated mercury, and that it makes up about $\frac{1}{5}$ of the air.

When Lavoisier heated the red powder that had collected in the retort, he obtained all the gas that had been lost by the air. When he applied to this gas the tests which Priestley had used for his "good air," he obtained the same results as Priestley. Lavoisier had thus proved that the air consists of **two substances,** one of them **active,** and able to support burning and life; the other, **inactive.** The active gas is **oxygen**; the inactive one, **nitrogen.**

27. How We Prepare Oxygen.— If we wish to use dilute oxygen, we do not need to prepare it, for nature has provided a large supply in the air about us. Why not remove the nitrogen of the air, and so get the oxygen unmixed with nitrogen? If we have air in the **liquid** form, this can be done; for the liquid nitrogen boils off more readily than the oxygen. If the nitrogen were the active gas, we might cause it to combine with some substance, leaving the oxygen. But we must remember that the oxygen is the more active gas (see § 24), and that burning bodies combine with the oxygen of the air, and leave the nitrogen. So, to prepare oxygen, we use certain chemicals that consist partly of oxygen, and get the oxygen out of them.

The most common way to obtain oxygen is to heat a mixture of two substances called **potassium chlorate** and **manganese dioxide.** The potassium chlorate is a white solid which melts when heated, and foams, or "effervesces," as the oxygen is given off. The manganese dioxide is a black solid which causes the potassium chlorate to give off its oxygen more easily.

The apparatus required for preparing oxygen is shown in Fig. 25. It consists of a glass test tube in which the oxygen may be formed, a stopper and delivery tube for carrying off the gas, and a bottle, filled with water, for collecting the gas. As the gas bubbles out of the end of the delivery tube, it pushes the water out of the bottle and takes its place.

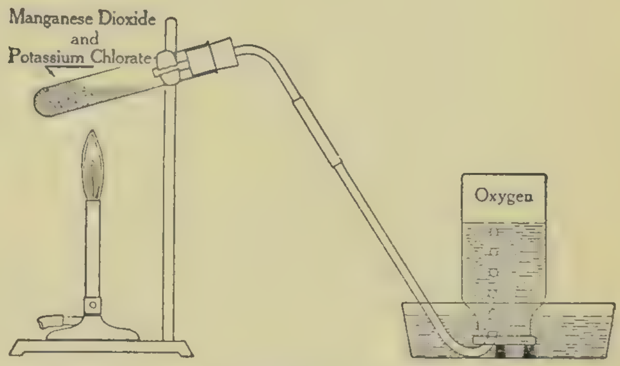


FIG. 25.
When we heat a mixture of powdered potassium chlorate and manganese dioxide by means of a small flame, we get a regular stream of oxygen.

To get oxygen enough to fill three or four 8-ounce (250 cc.) bottles, use about $\frac{1}{4}$ of a test tube of potassium chlorate and about $\frac{1}{8}$ of a test tube of manganese dioxide. These should be in the form of fine powders; mix them carefully on a sheet of smooth, clean paper. Heat the test tube with a very small, smoky flame (a candle flame is hot enough), and fill several bottles with the gas. As each bottle becomes full, slip under it a piece of cardboard, or of sheet glass, and set it right side up on the table. If the

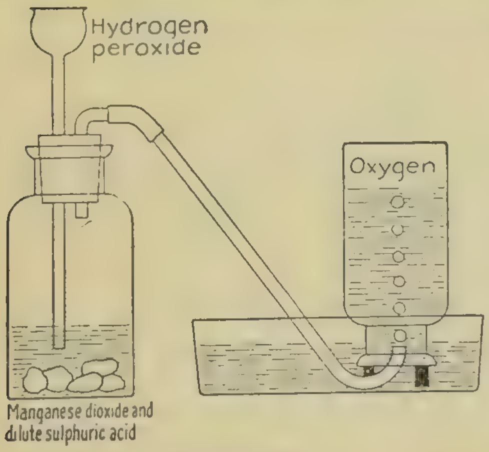


FIG. 26.
A safe way of preparing oxygen without the use of heat.

gas is to be kept a day or two, stopper the bottle tightly. Pint fruit jars with rubber rings and tight covers may be used to hold gases.

When you have collected enough oxygen, remove the delivery tube from the water; then, and not until then, remove the flame from the test tube. The reason for your being so careful is that as the gas in the test tube cools, it contracts. If the outside air forces cold water into the hot test tube, the tube may break. Use the gas for a study of the properties of oxygen (see § 28).

Another method of obtaining oxygen (see Fig. 26) is to pour a solution of hydrogen peroxide, a few drops at a time, into a bottle upon some manganese dioxide, or, better, potassium permanganate. just covered with water. No heating is necessary. The water foams as the oxygen bubbles off.

28. What Oxygen is Like.— We are now ready to learn some of the qualities, or **properties,** of oxygen. We can see, especially after the bottles of oxygen have stood for a moment, that the gas has no color. If pure, it has no odor or taste, either.

(1) Light a pine splinter, and put it for an instant into a bottle of oxygen; the wood burns much more vigorously than in air. Blow out the flame, and put the glowing splinter back into the bottle; the glow becomes very intense, and the splinter bursts into flame. This action serves as a **test** for oxygen; so that we can tell a bottle of oxygen from one of air.

(2) Sulphur, which burns with an almost invisible, blue flame in air, burns in oxygen with a flame that is brilliant and of a violet color. Hold the sulphur in a combustion spoon, and melt and light the sulphur in a burner before you put it into the bottle of oxygen. By smelling cautiously of the gas produced in the bottle you will find that it has the same sharp odor as the gas formed when sulphur is burned in the air. We call it sulphur dioxide.

(3) Fasten a wire to a piece of charcoal, or hold the charcoal in a combustion spoon, and set the charcoal on fire in a flame. The charcoal burns in air with a faint glow. Now put the glowing charcoal

into a bottle of oxygen, and you will find that the burning is vigorous, and gives off a brilliant light. The gas formed in the burning is carbon dioxide. It is colorless, like the oxygen itself, but you can test for it by means of a liquid called **limewater.** If you put this into the bottle in which charcoal has been burned, and shake it up with the gases in the bottle, it will become milky. The milkiness is due to an insoluble white solid produced when **carbon dioxide** and limewater unite. In a bottle of air or oxygen free from carbon dioxide limewater is not changed.

(4) Hold a burning candle, by means of a wire handle, in a bottle of oxygen. It burns with great vigor. Test the gas with limewater, as in (3).

(5) Iron does not burn readily in air, but it burns in oxygen. Put some sand into one of the bottles of oxygen, so as to cover the bottom completely. For iron use a piece of picture cord made up of fine strands of iron wire tipped with melted sulphur or the head of a match. Light the sulphur, or match head, and at once put the wire into the bottle of oxygen. The burning tip heats the iron to its ignition temperature (see § 22), so that it burns brilliantly in the oxygen. The shiny, black lump formed on the end of the wire is made up of iron and oxygen; it is iron oxide. The sand is used to protect the bottle from the hot iron oxide that may fall off.

Oxygen dissolves to some extent in water.

29. Oxygen and Fire.— We have already learned what burning is; it is the uniting of the material of the body burned with the oxygen of the air. Generally the same product is formed whether the body burns in air or in oxygen; why? Another way of saying the same thing is that burning is a form of oxidation. Oxidation means union with oxygen. We see that the word oxidation comes from the word oxide, which in its turn comes from oxygen. The substance which unites with oxygen is said to be oxidized. Thus the iron burning in oxygen is being oxidized to iron oxide; burning charcoal, which consists chiefly of carbon, is oxidized to carbon dioxide; burning phosphorus to phosphorus oxide. When lead is heated in the air, it is slowly oxidized to lead oxide, and tin to tin oxide. Powdered magnesium is burned to give the light for "flashlight" photographs; in the flash it unites with oxygen to give magnesium oxide. If we weigh the material burned, and collect all the material produced in the burning, we always find there is a **gain** in weight; this added weight is the weight of the oxygen which united with the burning body.

We think it is coal, fuel gas, and gasoline that give us heat and power (see § 50). We buy them for this purpose. But something else is needed: *oxygen.* Without oxygen our fuels do us no good. Do you realize that every pound of coal you burn needs about 2.5 pounds of oxygen to make it burn? So we heat our houses by means of oxygen as well as by coal.

30. Rusting and Decay.—Has rusting anything to do with the oxygen of the air? Perform the following experiment:

Wet the inside of a test tube with water and drain off most of the water. Now put some iron filings into the tube, shake them around, and pour out those that do not stick. Then set the tube, mouth downward, into a dish containing a shallow layer of water, and let the apparatus stand for a day or two. The iron rusts, and at the same time water rises into the tube. When no further change takes place, close the mouth of the test tube, under water, with your thumb and turn the tube right side up. Put into the gas that remains a burning splint. Does it continue to burn? What has the rusting iron removed? What gas is left? See §§24 and 32. About what fractional part of the air has been used up?

What becomes of all the iron produced in the world? Perhaps 72 millions of tons of it are extracted from its ores every year; but a great deal of this goes back into rust, by combining with the oxygen of the air. Rusting costs the people of the United States about $3,000,000,000 a year. The ores of iron are nearly all *oxides* of iron, similar to rust or to the substance formed when iron wire is burned in oxygen. As soon as the iron is obtained from its ores, it begins to rust, unless it is protected from the oxygen of the air. When iron is burned in oxygen, a great deal of heat and light are given off; in rusting, heat is given off, too, but very slowly. The product is also iron oxide. So we speak of rusting as a case of *slow oxidation*, to distinguish it from the rapid action which takes place in burning.

What other metals rust, or tarnish, in the air? With what materials is iron covered to protect it from rusting?

Decay.— Have you ever thought what becomes of the dead bodies of plants and animals and of dead leaves, wood, and fruit? We say they rot, or decay. Decay, like rusting, is due to **slow oxidation.** Some kinds of **bacteria** (see §§ 86 and 91) bring about the decay, and use up oxygen in the process. Oxygen is thus not only the supporter of combustion, but the world's purifier; for it changes the remains of former life into harmless substances, so that new life may have its opportunity.

What is the construction of a "hot bed," in which vegetables may be grown in winter or early spring? It is a shallow box with a glass cover; the lower part of the box is surrounded by manure. Heat is given off by the decay, or oxidation, of the manure, and keeps the ground and inside of the box warm, so that vegetables will grow there safely, even in freezing weather.

31. Why Paint Hardens.— Do you think painting has anything to do with oxygen?

Wet the inside of a test tube with "boiled" linseed oil; then let most of the oil drain out of the tube. Now set the tube, mouth downward, into a dish containing a shallow layer of linseed oil (Fig. 27), and let the apparatus stand for a day or two. The oil rises part way (how far?) up the tube, and then stops. Why?

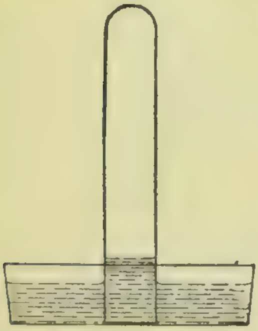


FIG. 27. Linseed oil combines with the oxygen contained in the air of the test tube.

Common **paint** is a mixture of linseed (flax seed) oil, turpentine, and "white lead," with perhaps some coloring material. The white lead gives the paint "body," or covering power. The turpentine thins the paint and assists in drying the oil. When paint dries, its linseed oil absorbs oxygen from the air and combines with it to form a hard gum. You have probably seen this gum as a scum upon paint in an open can. The gum does not dissolve in water, and is not easily washed off; hence it protects the painted object from the decaying action of the air. The heat given off in the oxidation of linseed oil often sets painters' cloths on fire "spontaneously."

32. What Nitrogen is Like.— Nitrogen, as we have seen, does not support combustion; it does not support life, either. It not only does not unite readily with other substances, but it escapes easily from most materials that contain it. Thus when leaves, stubble, and grass are burned, the nitrogen they contain passes off into the air. Nearly all our explosives are substances which hold nitrogen loosely, so that when the explosive is set on fire, or given a shock, the nitrogen is set free with great violence. The nitrogen and other gases formed exert **great pressure,** and **do work,** such as the hurling of a projectile or the tearing apart of great masses of rock. Name the common explosives we use.

While nitrogen itself does not support life, it forms a part of all **proteins,** substances needed to build up all living cells. It is therefore a necessary part of all animals and plants. Such foods as meat, cheese, eggs, and milk are largely proteins.

Animals must get their proteins from the plants upon which they feed, while plants, in their turn, make proteins out of the carbon, hydrogen, oxygen, nitrogen, and other materials which they obtain from soil, water, and air. Most plants cannot take up nitrogen directly from the air; but such plants as beans, peas, clover, and alfalfa seem to do so. These plants have this power because of the "colonies" of bacteria—microscopic plants — which attach themselves to their roots (Fig. 28). It is the nitrogen-fixing bacteria that take the nitrogen out of the air and build it into the complex materials upon which the beans and other plants feed, and the excess of these materials remains in the soil, to serve as food for plants

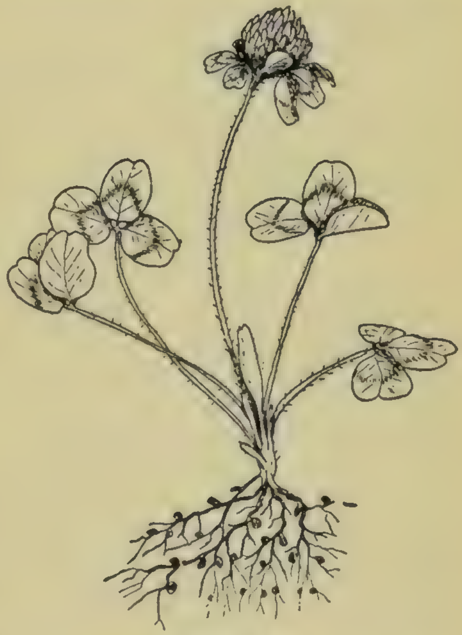


FIG. 28.
A red clover in blossom, with tubercles on its roots.

that cannot take up nitrogen directly. Farmers grow clover and "plow it under," in order to enrich soil with nitrogen compounds for the use of grain crops, such as wheat. It is because they contain so much nitrogen that beans, peas, and similar plants are such valuable food for man and animals.

Liquid Air.— Liquid air is really a mixture of liquid nitrogen and oxygen, with small amounts of other materials. Air cannot be made liquid except at a low temperature and by great pressure. It is about as heavy, volume for volume, as water. It boils at about −190°C.

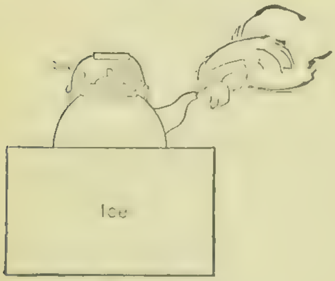


Fig. 29, *a*.
Liquid air is so cold that a cake of ice serves as a stove, and makes it boil furiously.

If alcohol is put into liquid air, it becomes a solid, like ice. Mercury freezes to a hard metal, and a hammer made of it may be used to drive nails. Rubber becomes brittle, and flies into pieces when thrown upon the floor. A piece of meat acts in the same way. If liquid air really *wets* the skin, it burns it like hot iron; but you can put your hand into the liquid for a moment without injury, because some of the liquid next the hand is turned into gas, and the layer of gaseous air covers the hand like a glove (Fig. 29, *a*).

Liquid air is constantly evaporating; it is therefore kept in *open* vessels, called **Dewar bulbs,** to avoid explosions (Fig. 29, *b*). These have double walls, and the air is removed from the space between the walls, so that heat from the outside cannot affect the liquid within. The walls are *silvered* for the same reason. Thermos and Caloris bottles and **fireless cookers** (see § 53) are made on the same principle as Dewar bulbs, to keep a cold liquid from becoming warm and a hot one from becoming cold.

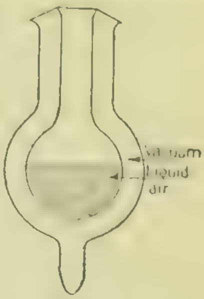


Fig. 29, *b*.
A Dewar bulb containing liquid air.

33. Summary.— Fire travels by raising fresh portions of the combustible to the **kindling temperature.**

Fresh supplies of air are needed to allow burning to go on.

Only about $\frac{1}{5}$ of the air supports burning; this is **oxygen.**

The chief inactive gas of the air is **nitrogen.**

Burning in air is the rapid uniting of the burning body with oxygen; it is **oxidation.**

Oxidation may be **slow,** as in rusting and decay, or **rapid,** as in burning, or **combustion.**

A **flame** is a burning gas.

We **prepare oxygen** by heating a mixture of powdered potassium chlorate and manganese dioxide, or by putting hydrogen peroxide with potassium permanganate.

Oxygen is a colorless, taseteless, odorless gas, slightly soluble in water. Bodies which burn slowly in air burn vigorously in oxygen.

Nitrogen is a part of most explosives, and of all proteids, a class of foods necessary for all life.

Liquid air boils at about —190° C. It must be kept in vessels which are nonconductors of heat.

34. Exercises.— 1. If we wish to put out a fire, what must we keep away from it? Why does a blanket or rug put out a fire?

2. Why do we use, first, paper, then wood, and then coal in starting a coal fire?

3. Does the air which passes out of the fire through the stovepipe contain more, or less, than 21% of oxygen?

4. Why does a sharp puff of air put out the flame of a lamp or candle?

5. Why does gentle blowing cause a glowing ember to burst into flame? Why are bellows used for charcoal fires?

6. Why does a kerosene lamp or stove have a chimney? What does the chimney cause to come to the flame? What does it carry away?

7. What name can you give to the substance formed when zinc dust burns in air? When mercury is oxidized to a red powder? When copper is oxidized?

8. Why does covering wood with an oxide protect it against fire?

9. Make a list of objects made of iron which rust readily and have to be protected.

35. Projects.— 1. Make a list of all the materials used to protect iron from rusting, and prepare a set of samples. 1 in. square, of protected iron.

2. Determine if the steam escaping from a teakettle is combustible or a supporter of combustion.

3. Put out a fire (built in the yard) by means of an old blanket or towel. Repeat, using a mixture of equal weights of baking soda and sawdust.

4. Put out a fire by means of a Pyrene fire extinguisher, and prepare a report upon the working of this apparatus.

5. Examine an old stove, and determine if it shows any signs of being partly burned up.

6. Distinguish between the contents of 3 bottles containing oxygen, nitrogen, and air respectively.

7. Prepare oxygen from hydrogen peroxide and potassium permanganate (see § 27).

8. Prepare oxygen by heating red precipitate (mercuric oxide).

9. Prove that carbon dioxide is being formed in the burning of coal in a stove. In a gas jet.

10. Determine if oxygen (not air) will rust iron, and how much of the gas is used up.

11. Determine if paint will absorb oxygen as linseed oil does (§ 31).

12. Determine if a rusting "tin" can gains in weight.

13. Make a list of materials used to protect wood from decay, and prepare a set of samples of such substances.

14. Collect specimens of clover, alfalfa, and similar plants, and demonstrate the presence of tubercles on their roots.

15. Put out a soot fire in a furnace flue by means of a few spoonfuls of baking soda.

SUGGESTION:—Put the soda, a tablespoonful at a time, into the "check damper" opening, between the furnace and the flue.

16. Prepare a report upon the construction of the oxy-acetylene torch and its uses.

17. Demonstrate the use of the wick and burner of a kerosene lamp.

18. Prove that a constant supply of fresh air is necessary to enable a candle or lamp to continue burning.

36. References.— FARADAY: *A Chemical History of a Candle.* HENDRICK: *Everyman's Chemistry.* HESSLER AND SMITH: *Essentials of Chemistry.* KAHLENBERG AND HART: *Chemistry and Its Relations to Daily Life.* SMITH AND JEWETT: *Introduction to the Study of Science.*

CHAPTER IV

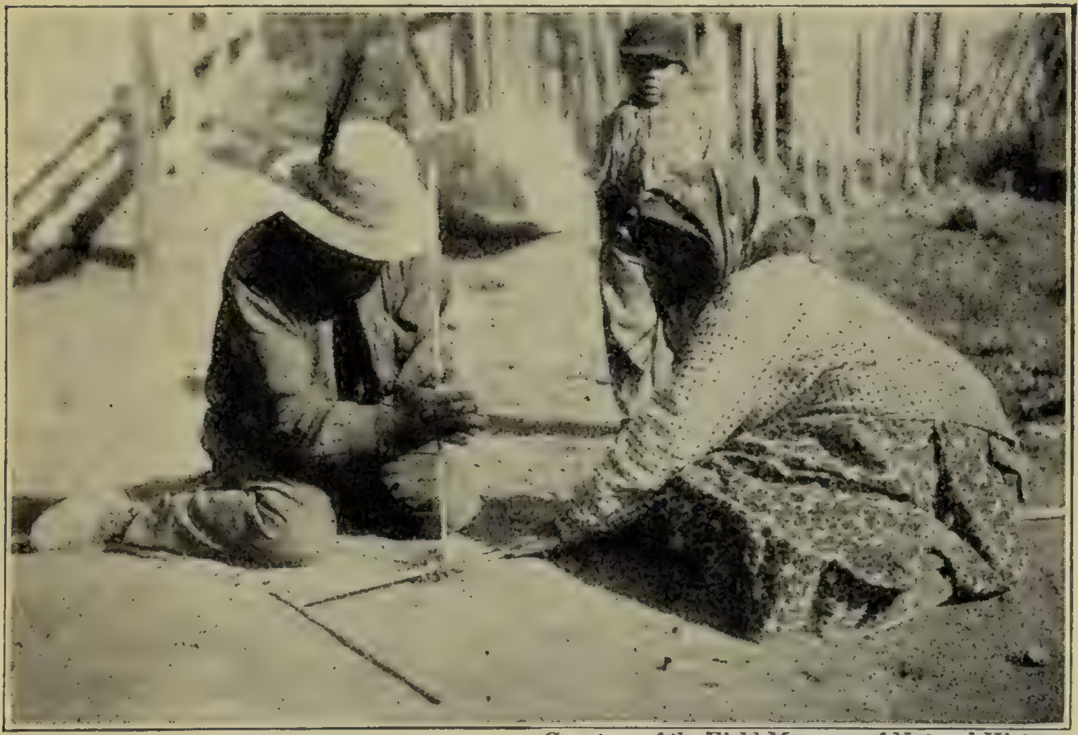
HOW WE HEAT THE AIR

37. Heating the House.— When we say that we "heat" the house, do we not mean that we heat the **air** of the house? The walls, floors, and furniture of the house take heat from the warm air, and so become warm themselves.

FIG. 30.
Fireplaces give added warmth, beauty, and ventilation to a house.

In winter we try to "keep in the heat," or "keep out the cold," meaning the heated, or the cold, air.

To heat the air of their houses men have used many methods. We think at once of stoves, hot-air furnaces, and hot-water, steam, and electric heaters. It is hard for us to realize that these are all modern methods of heating, and that our great-grandparents lived at a time when all the artificial heating and much of the lighting were done by the open fireplace (Fig. 30) with wood for the fuel. The Indian built a fire on the floor of his wigwam, and let the smoke escape through a hole in the top. The Eskimo uses blubber (whale fat) as the fuel to heat and light his igloo.



Courtesy of the Field Museum of Natural History.

FIG. 31.

How a Washoe Indian can kindle a fire. He turns the drill rapidly between his hands, so that it rubs against the horizontal stick, or hearth. The friction produces not only heat but also a little heap of wood meal, which forms the tinder. Finally the wood meal begins to burn.

No modern method of heating brings into the house the cheer that belonged to the **fireplace**; hence men try to use it as an ornament, no matter what system is used for the actual heating. But the fireplace is more than an ornament; for it is one of the best means of ventilation (see § 72), because it carries out the foul, cooled, lower air and makes room for the warmed, fresh air that is so much needed for health and comfort.

The tools of the fireplace were interesting. One was the **crane,** a swinging frame from which the cooking utensils were hung. The **andirons,** or "dogs," held the fuel up from the hearth, so that air might have free access; why? In large fireplaces a huge **backlog** was used. This was placed at the back of the fire, and smaller pieces of fuel were placed in front of it, on the andirons. The backlog often lasted several days, and from it the new fire was built in the morning. We must remember that not only the heating and lighting, but also the cooking and baking, were done by the heat of the fireplace.

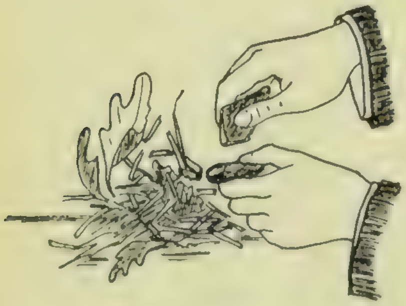


FIG. 32.
How fire was kindled by means of flint and steel.

38. Kindling a Fire.—How did men learn to kindle a fire? Many primitive peoples still start their fires by rubbing one piece of wood against another (Fig. 31). The friction gives the temperature needed to set tinder on fire. Tinder consists of bits of bark, pitch, dry fungus, and similar materials that are easily ignited. A century or so ago the kindling method used in Europe and America was the **flint-and-steel.** That is, a piece of flint (a kind of rock) was struck with a bar of steel (Fig. 32) and produced hot sparks which were caught in tinder. In the **flintlock** musket this method was used to kindle gunpowder.

The first practical **matches** were made about 1827. They consisted of wooden splints, partly coated with sulphur, and tipped with potassium chlorate (the substance used in the preparation of oxygen; see § 27), antimony sulphide, and a gum. When the match head was rubbed against a rough surface, heat enough was produced (see § 50) to allow the sulphur to unite with the oxygen of the potassium chlorate. The heat of the burning sulphur set the wooden splint afire.

Modern matches are ignited more easily than these first ones, because they contain phosphorus, or a substance called *phosphorus sulphide,* but the principle of their action is the same. There must be substances which are easily set on fire, and there must be something to furnish oxygen rapidly to these substances.

Safety matches are somewhat less convenient to use than strike-anywhere matches, because they must be struck against the surface of a box; but they are not so likely to cause accidental fires, and are therefore safer to have about. The striking surface of the safety-match box is red phosphorus and sand; the tip contains antimony sulphide, some oxidizing substance (what one might be used?) and glue. Is red phosphorus the most active form of phosphorus? See § 24.

39. How Stoves Work.— The **fireplace** is an open fire, much like a bonfire, but with a flue, or chimney for the escape of waste gases. The whole fireplace opening allows fresh air to enter to replace that which is used up. In a **stove** the heat set free by the burning fuel can be used in a more economical and convenient way than in the fireplace. The fire is surrounded on all sides. Dampers control the entrance of air, and a pipe carries off the waste gases. In place of andirons there is a grate; this holds the fuel up, so that air may pass through it. In a **cookstove** (Fig. 33) both the top of the stove and the oven must be heated, hence there is a "back damper," which does not allow the hot, waste gases to escape at once, but compels them to travel in a roundabout way, heating a large surface of the oven before they leave the stove. Examine a heating stove or a cookstove carefully, and trace the path of the air through it.

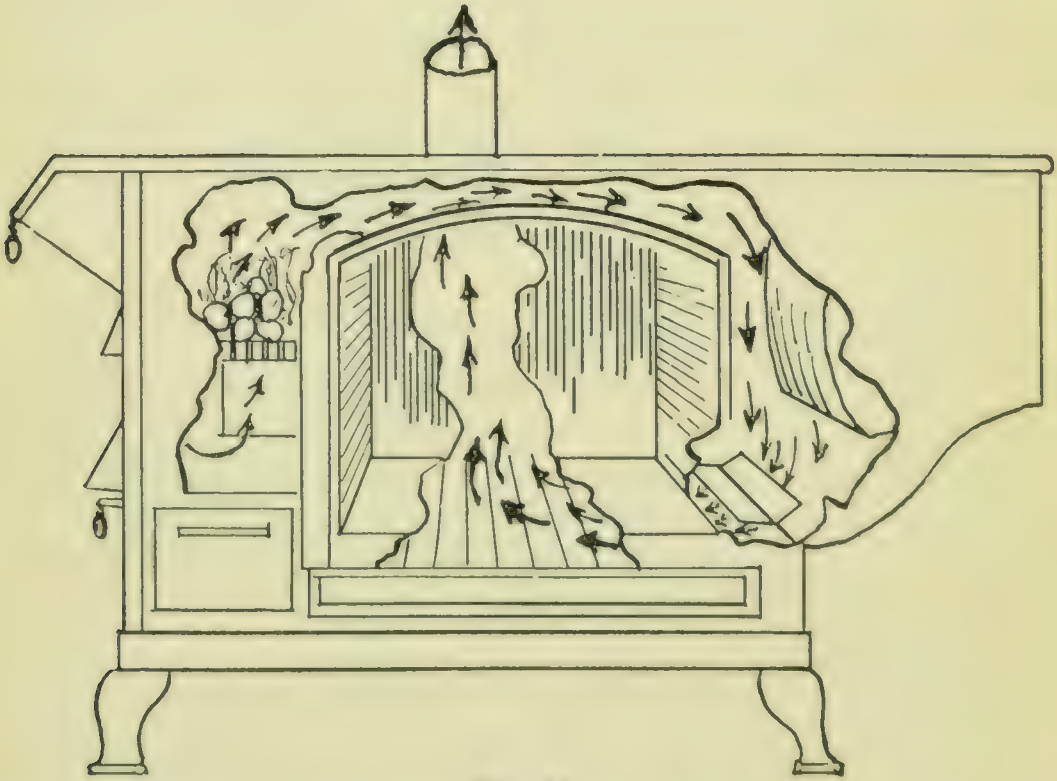


FIG. 33.

In a cookstove the back damper compels the hot gases of the fire to heat the oven before they escape.

40. Gas and Gasoline Stoves.— Gas stoves have taken the place of wood and coal stoves, wherever gas can be obtained. The gas used for lighting has a smoky flame, and deposits soot. To avoid the soot, and to secure a hot flame, we use the principle of the **Bunsen burner** (Fig. 34). In this burner the gas escapes through a pinhole into a mixing tube. The tube has air holes near the place where the gas enters. The small, rapid current of gas that enters the mixing tube draws air into the tube, and the mixture of air and gas burns at the top of the tube. The flame is smaller than if the gas were burned directly; but it is also hotter. Since the gas is mixed thoroughly with air, it is completely **oxidized** (see § 25) and the flame is smokeless. **Smoke,** or soot, *represents wasted fuel.*

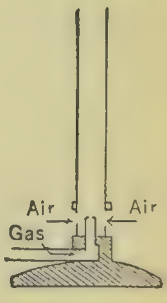


FIG. 34. The Bunsen burner gives a hot, smokeless flame.

If the supply of air taken in by the Bunsen burner is too great for the amount of gas, there is a slight explosion in the mixing tube, and the flame "strikes back" to the gas inlet inside the burner. If we regulate the gas supply and the size of the air holes, this will rarely take place. In **gas stoves** (Fig. 35) the air holes are at the front near the openings through which gas enters.

The **gasoline burner** is essentially a Bunsen burner. To light a gasoline stove we run some of the gasoline into a "cup," and there burn it to heat the **vaporizer.** When the vaporizer is hot, we allow the liquid gasoline to enter it very slowly; it is there changed to the form of a gas. Air is drawn into the burner by the current of gasoline vapor, and the mixture burns at the top of the burner with a very hot flame, as in the case of gas itself.

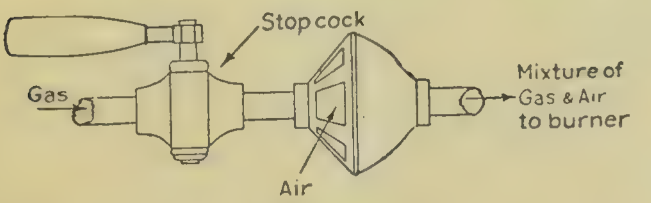


FIG. 35. The gas stove is a Bunsen burner. The gas is mixed with air; hence the flame is smokeless.

The use of **gasoline** is attended with danger unless the stove is of good construction, and unless great care is taken in handling it. People think of gasoline as a liquid. They should rather think of it as a gas. What is it called by automobile drivers? It boils very low (60° to 70° C.), and what seems to be only a little of the liquid may give a great deal of the vapor. The vapor forms a very explosive mixture with air. Reservoirs should not be filled when fires are anywhere about, and if any gasoline is spilled, the room should be thoroughly aired before a burning body is brought into it. Why is the engine of an automobile stopped while the reservoir is being filled?

Kerosene burns with a smoky flame, and has a high boiling point (150°—250° C., see § 25); hence burners using it must have hotter vaporizers and a greater air supply than gasoline burners, or must have wicks.

41. How a Hot-Air Furnace Works.— Which is heavier, volume for volume, cold air, or warm air? Carry out the experiment suggested in Fig. 36. If you have no flasks, use two inverted small-mouth bottles, and heat one of them carefully either with the flame or hot water. Cool the other one. What effect has heating a given volume of air? Cooling it?

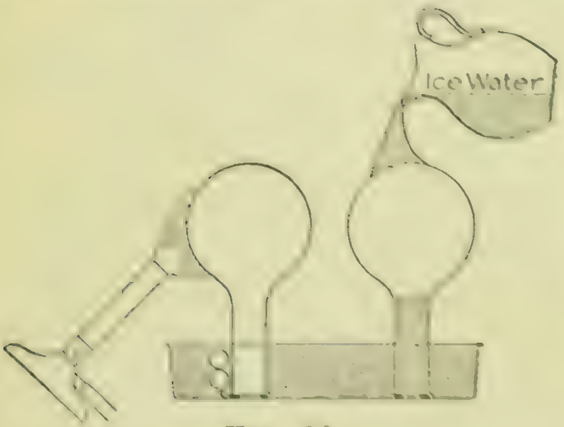


Fig. 36.
The air in the heated flask expands; that in the cooled flask shrinks, or contracts.

Review Project 2, §20, also § 9. If you were to fill the flask shown in Fig. 7 with air at the room's temperature, and were to weigh it, and were then to open the stopper, heat the flask, and weigh it again, would the warm air in the flask weigh as much as the unwarmed air? What would be the effect of filling the flask with the cold air of a refrigerator, and then weighing it?

If you push a cork under water, and let go of it, what happens? It rises to the top. What really happens is that the water, which is heavier, pushes itself into the space occupied by the cork and forces the lighter body to the top. Does anything of this sort take place in the air of a house heated by a hot-air furnace?

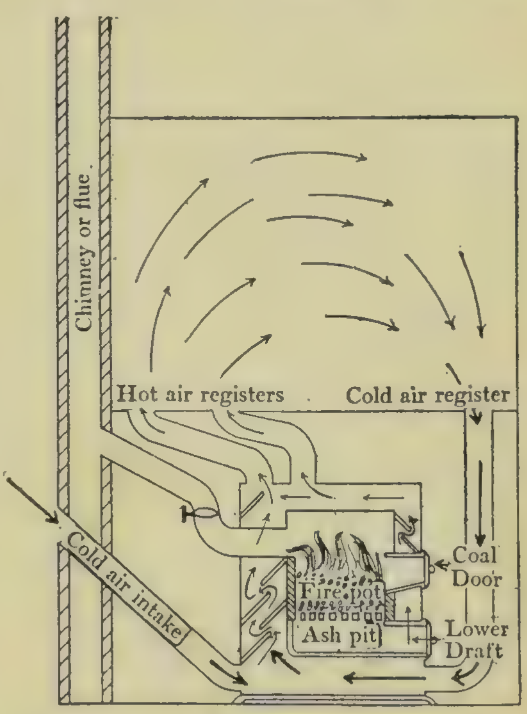


FIG. 37.
A hot-air furnace is a stove surrounded by a "drum" from which convection currents carry warm air to the rooms of the house.

Examine a **hot-air furnace** (Fig. 37). The air is heated in a tight "drum" which entirely surrounds the firepot of the furnace. When the firepot is hot, ascending air currents are formed in the drum, and rush through the open registers into the rooms of the house. When this heated air has given up enough heat to the walls, the furniture, and the air of the room, it becomes cool, and therefore heavier, and falls to the floor. It then finds its way through the cold air register, back to the drum to be reheated. Study Fig. 37 carefully, so as to understand the way in which the hot-air furnace works. In order that some fresh air, direct from outdoors, may be brought into the house, the furnace usually has a "cold-air intake."

Are there any air currents in a **refrigerator?** See § 52 and Fig. 46. In order to cool the whole refrigerator most efficiently, where should the ice be placed, near the bottom, or near the top?

42. How a Fire Warms Us.— If you put a flatiron on a hot stove, the heat of the stove is passed over, or **con-**

ducted to the iron. If you touch the hot iron, its heat is **conducted** to your hand. To hold a hot flatiron, you use a **nonconductor** of heat, such as a pad of cloth or asbestos, or a wooden handle. If you touch a cold object, your body's heat passes **to the object.** That is why the object **feels** cold. The colder object is warmed by conduction from the warmer one. The air that touches a stove or steam radiator is also warmed **by conduction.**

How are you warmed when you sit before a fireplace? The heat of the fire comes to you whether you are above the fire, or below it, or on one side, just as the light of a lamp does. The heat of the fire, like the light of the lamp, is **radiated** to you. "Radiated" comes from *radius*, a ray, or the spoke of a wheel. The heat of the sun, as well as its light, comes to us by radiation through space. There are, then, two ways in which heat comes to us from a hot body or a fire: (1) by **conduction**; (2) by **radiation,** in the form of heat rays.

We often speak of a **third** way of distributing heat: by **convection.** This means the rising of air when warmed, and its falling when cooled, as in the hot-air furnace and refrigerator (see § 41). This is really not a new way at all, because in order that the air may rise in convection currents, it must first be warmed by touching a hot body (conduction) or by means of heat rays (radiation).

43. Heating by Hot Water.— We have seen that heated air is lighter than cool air, and therefore rises in convection currents, and that this fact is the principle upon which the hot-air furnace works.

Perform the following **experiment** (Fig. 38), so as to find out if water can form convection currents, as air can:

Into a glass dish (beaker, flask, or large test tube) nearly full of water put a little sawdust or small bits of paper, and warm the dish carefully. Follow the movements of the sawdust or paper. Are there convection currents in the water?

The heated water acts like heated air. It is lighter than the cooler water and rises to the top, while the cooler water from the top falls to the bottom.

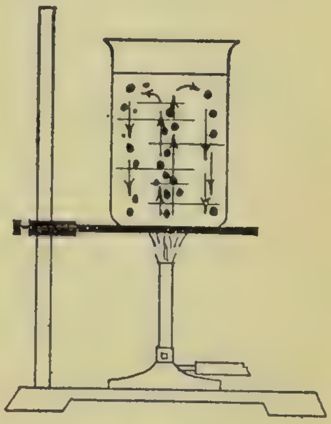


FIG. 38.
The convection currents in the heated water are made visible by the movements of bits of wood or paper.

If you examine a **hot-water heating system** (Fig. 39), you will find that it consists essentially of a **furnace** in the basement and **radiators** in the rooms. The firepot of the furnace, instead of being surrounded by air, has around it a "jacket" of water to be heated. Convection currents in the water carry hot water to the radiators and bring back the cooled water through "return" pipes to the furnace, to be heated over again.

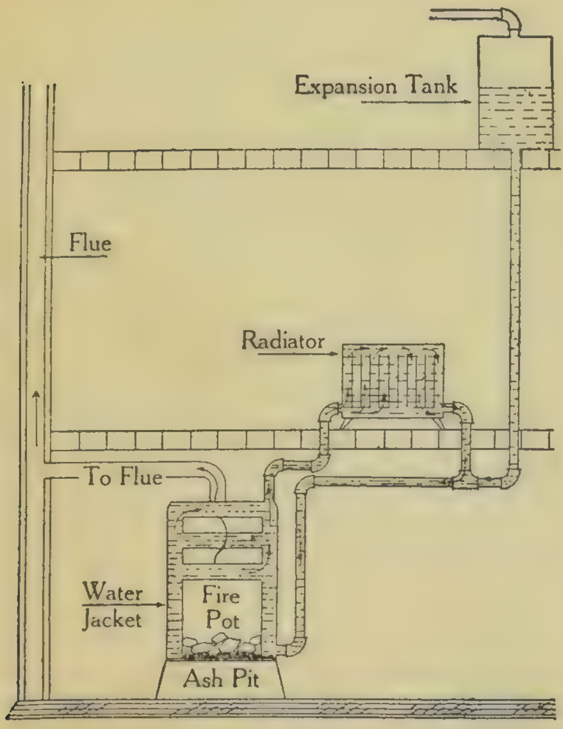


FIG. 39.
Hot-water heating systems depend upon the convection currents formed in the water heated by the firepot.

44. Heating by Steam.—Examine a **steam-heat-**

ing system (Fig. 40). You will find that the essential things about it are a **boiler** partly full of water, a **furnace** to supply heat, and **radiators** for the rooms. The furnace not only heats the water until it boils, but changes some of the liquid water into a gas. We call this gas "steam." Steam is like air, but with this difference: the steam can change back easily into a liquid.

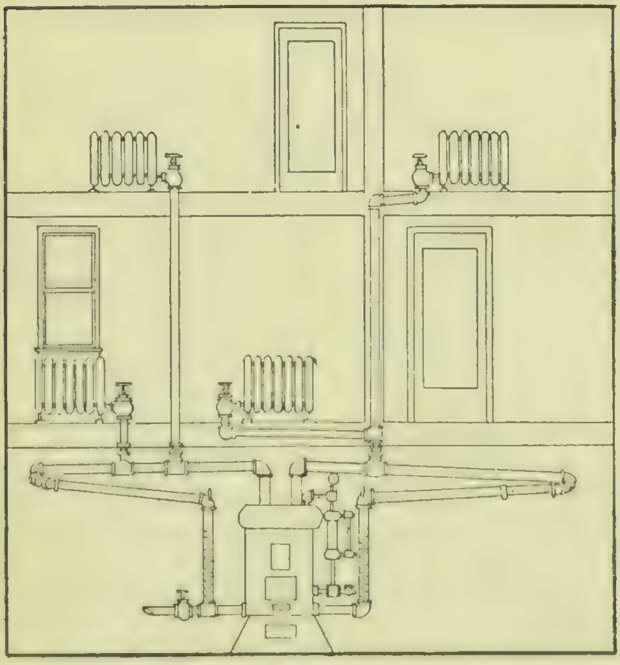


Fig. 40.
Heating by steam depends on the fact that the heat stored in the steam is set free when the steam condenses to water.

Carry out the following **experiment**: Weigh a dish (beaker or tin cup) containing some water, and heat the water to boiling. Hang a thermometer so that its bulb is in the boiling water. Let the water boil for 10 to 15 minutes until a considerable amount has boiled away. Then weigh the dish and water again. How much was lost? What becomes of the water? From time to time during the boiling notice the reading of the thermometer. Does the water become any hotter as it boils away? What becomes of the heat that is added to the water after it begins to boil? This heat is used to change liquid water into the gas steam, which escapes.

In steam heating a **new principle** is used: the heat comes from the **condensation** of gaseous steam to liquid water. We store away in steam the heat given off by the burning fuel, carry the heat to the radiators, and then get it back by allowing the steam to condense, in the radiators, to liquid water. So we could have steam at 100° C. entering a radiator and water at 100° C. leaving it; yet the room would receive a great deal of heat.

45. Heating by Electricity.— We know that our electric-light bulbs contain very thin wires, or **filaments,** of certain materials, and that when the current passes through these, it gives off light and some heat. See §§189 and 190. Filaments of carbon or platinum were originally used; the Mazda lamp has filaments of a rare metal called **tungsten.** If we pass the current through thicker wires of German silver or nichrome (nī′krōm), we get no light, but much heat. Nichrome is an alloy, or mixture, of the metals nickel and chromium; it is much used in apparatus like electric stoves, irons, heating pads, and toasters. See Fig. 179, § 189.

The great advantage of electric stoves is that they need no chimneys, and they heat without fuel or odor. They do not use up the oxygen of the air, either. They are used in trolley cars, in elevators, and in many places in which it would be hard to set up other apparatus for heating. Some houses already have electric stoves, but such stoves seem too expensive at present for general household use. Some day they will probably displace all other forms of heating.

46. Exercises.— 1. In what way are gasoline cans commonly distinguished from those for kerosene? Why?

2. Suggest some ways of kindling a fire without the use of rubbing, or friction.

3. Show that the cookstove is an improved form of fireplace.

4. What is the cause of the "pounding" often heard when steam is first turned on in a cold radiator?

5. Why can ice cream be carried in a *paper* box through heated air, and yet melt very little? Would a tin box keep it better? Why?

6. What materials are used for the handles of teakettles? Why?

7. If you put the bowl of a silver spoon into a cup of hot water, the handle becomes hot. Why? Put an iron ("tin") spoon and a solid silver spoon into a cup of hot water at the same time. Which handle becomes hot the sooner? Why?

8. Should hot-water and steam pipes be put near the floor, or near the ceiling, in order to heat the room? Why? Where should the cold-brine pipes be put in a cold-storage room in order to cool the room? Why?

9. Why does air enter a stove or furnace at the bottom and go out higher up?

10. Why are houses built with double walls having air spaces between them?

11. What method of heating is used in your house? In your school?

12. What are some of the advantages of the different heating systems? Some of the disadvantages?

47. How We Determine Temperature.— What is the meaning of **temperature?** It is the **degree of heat or cold.** We get some idea of temperature from the nerves of the skin, but not a very accurate one.

Carry out the following **experiment** to learn how unreliable our sense of temperature is: Put some cold water into one basin, lukewarm water into another, and hot (not scalding) water into a third. Put one hand into the cold water and the other hand into the hot water; after a moment put both hands into the lukewarm water. To the cold hand the lukewarm water feels hot, to the warm hand the lukewarm water seems cold. Yet you know that both hands are in the same basin of water.

Put your hand on some oilcloth and on a woolen rug; which seems colder? The oilcloth does, because it conducts heat away from your hand; but the two have really the same temperature. To get temperature accurately, we cannot depend upon our sense of temperature, but must use a **thermometer.**

The common thermometer consists of a glass tube having a bulb at one end. The bulb and part of the tube contain mercury. The inside of the tube is of very small bore, so that if the mercury expands only a very little in the bulb, it will force a long thread of mercury into the tube. Sometimes alcohol is used as the liquid in the bulb and tube. This does not freeze at the lowest winter temperature of the Arctics.

When the thermometer is made, the end of the tube is left open, and enough mercury is used to fill the bulb and *part* of the tube. The bulb is then heated until mercury fills *all* the tube; the open end is finally sealed. When the mercury in the bulb cools, it contracts, and the thread of mercury again fills only part of the tube.

To make a thermometer useful, we must "graduate" it, or mark it in "degrees." First we put the bulb into **melting ice** (Fig. 41,*a*) and mark the place on the tube at which the mercury

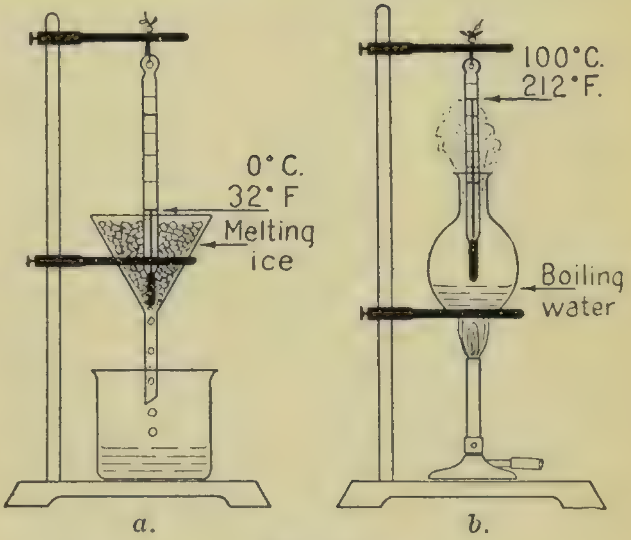


FIG. 41.

a. The "freezing point" of a thermometer is the temperature of melting ice. *b.* We get the "boiling point" by putting the thermometer in the steam escaping from boiling water.

stops contracting; this is the **freezing point.** Then we put the bulb into the steam coming off from **boiling water** (Fig. 41, *b*), and call the place at which the mercury stops expanding, the **boiling point.**

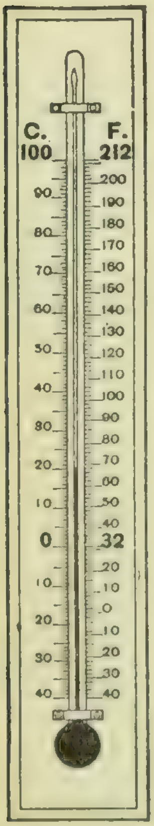


FIG. 42. A thermometer with both Fahrenheit and Centigrade readings.

48. The Two Thermometer Scales.—You will see that almost any number might be given to the freezing point and the boiling point of the thermometer. **Fahrenheit** (fä′-rĕn-hīt) called the freezing point, 32° F., and the boiling point 212° F. Between them he marked off 180 equal degrees (Fig. 42).

In the **Centigrade** thermometer (abbreviated **C.**) the freezing point is 0° C. and the boiling point, 100° C.

If the tube of the thermometer has the same bore, or opening, throughout its length, we can mark degrees *above* the boiling point and below the freezing point, as well as *between* these points. Thus, if we make a mark as far above 100° C. as the zero mark is below 100° C., the new mark will be 200° C. In this way we can mark mercury thermometers up to the temperature at which mercury boils (357° C.) and down to that at which it freezes (—39° C.). Why would not water do as well as mercury for a thermometer? What advantage has alcohol? See § 47.

The number of degrees between 32° and 212° is 180; consequently 100 Centigrade degrees equal 180 Fahrenheit degrees. Each Fahrenheit degree is, therefore, $\frac{5}{9}$ of a Centigrade degree, and each Centigrade degree is $\frac{9}{5}$ of a Fahrenheit degree. If we multiply the number of degrees shown by a Centigrade thermometer by $\frac{9}{5}$, and then add 32, we get the Fahrenheit reading.

$$\textbf{Fahr.} = (\textbf{Cent.} \times \tfrac{9}{5}) + 32.$$

If we subtract 32 from the Fahrenheit reading, and then multiply the remainder by $\frac{5}{9}$, we get the Centigrade reading.

$$\textbf{Cent.} = \tfrac{5}{9}\ (\textbf{Fahr.} - 32).$$

The Centigrade scale is used almost everywhere on the continent of Europe, and practically everywhere, the world over, for scientific work.

49. What is Heat?— Have you ever seen a blacksmith put an iron tire on a wagon wheel? Watch one, if possible. He **heats** the tire first, so as to make it large enough to go on the rim. Then, as it cools, the tire contracts and grips the rim tightly, and drives the spokes into the hub. This is a very practical use of the fact that iron expands when heated and contracts when cooled.

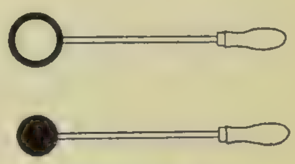


FIG. 43, *a*. When both ball and ring are at the same temperature, the ball goes through the ring.

If possible, carry out the experiment with the brass ball and ring (Fig. 43). The ball just goes through the ring when both are cold. If the ball alone is heated, it is too large for the ring; but if the ring, too, is heated, both expand the same amount, and the ball now goes through the ring.

A **liquid,** like water or kerosene, which just fills a flask at the temperature of the room, more than fills the flask when heated, but does not fill it when cooled. A **gas** expands and contracts as a solid or liquid does, but to a greater extent. Thus, if a flask of air is heated (see §41), some of the air escapes; but the volume of the air becomes smaller if the flask is cooled.

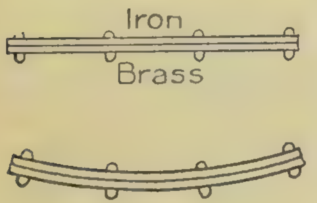


FIG. 43, *b*. A piece of brass and one of iron riveted together. When they are heated, the brass expands more than the iron, and the bar is bent.

How can we explain these changes in volume of solids, liquids, and gases? It is hard to see how the volume of a body can change unless the material of the body consists of particles, with **spaces** between them. Then we can explain the shrinkage that occurs when a body is cooled by saying that the particles are crowded closer together when cold. Scientists have very good proof that the objects we know really consist of such small particles, or **molecules** (mōl′ē-kiuls; *little masses*). The molecules are **in motion.** Each molecule needs a portion of **space** in which to move about; so that the volume of a body is the sum of the spaces needed by all the moving molecules, in addition to the volumes of the molecules themselves.

Heat is the energy of the moving molecules. When we add heat to a body, each molecule moves more rapidly, and pushes its neighbors farther away. Hence the distance between molecules becomes greater, and the volume of the body increases. We assume that the volumes of the molecules themselves remain unchanged. When we **subtract** heat from a body, that is, cool it, the molecules need less space for their motion, and the body's volume shrinks.

Molecules are very **small.** Scientists estimate the number of molecules in 1 cu. cm. of a gas as about 27 million million millions (27,000,000,000,000,000,000).

50. Sources of Heat.— The chief sources of heat are the sun, body heat, burning fuels, friction and collision, and electrical resistance.

The **sun** is the chief source of the warmth of the earth's surface and of its atmosphere (see §§ 128 and 152). The earth gets some heat from the moon (see § 154) and stars and its own interior, but the amount is small. The gain and loss of the sun's heat in the temperate and frigid zones causes the seasons of these zones (see § 162).

Man is the only animal that uses **fire.** Other animals and the world of plants store up some of the energy that comes from the sun, and man uses them for **food** and **fuel.** In causing food and fuel to unite with oxygen, man is getting back some of the sun's energy (see §§ 29 and 71). The chief fuels are coal, wood, charcoal, coke, natural gas, petroleum, and alcohol. **Petroleum** is the natural product out of which gasoline, kerosene, and paraffin (white wax) are prepared. Illuminating and fuel gas are prepared from coal (see §§ 59 and 200). We have already learned something about **electric heating** in § 45.

How do **friction** and **collision** produce heat? If you slap your hands together briskly, they become warm. When a nail is struck by a hammer, or a bullet is stopped by a rock, the nail or bullet becomes hot. Why? The moving bodies: hands, hammer, or bullet, have their **motion** changed into **heat.** The motion of the mass as a whole is changed into the motion of the invisible molecules (see § 49).

Early man learned in some way to use friction to kindle his fires, and thus changed muscular energy into heat (see Fig. 31). In the modern **match** man is still exchanging motion for heat; for he uses friction to kindle the match (see § 38).

51. How Heat is Measured.— We have learned that the **temperature** of an object is its hotness or coldness, that is, its **degree of heat.** Boiling water has a temperature of 100° C., lukewarm, about 40° C., and cold, 0° to 10° C. It makes no difference how much water you have; a cupful of boiling water has the same temperature as a pailful. But has it the same **amount** of heat? If you heat water to boiling over a gas burner, which requires the longer heating, the cupful or the pailful? If you used the water to warm yourself, which would give you the more heat? In a house heated by hot water we know that a large room requires a greater amount of hot water, that is, a larger radiator, than a small room does. So we say that the amount of heat in an object, or body, depends not only upon the temperature of the object, but also upon how much there is of it (its **mass**; see § 109). The amount of heat in a body depends also upon the **kind of material** of which the body is made up.

We need a **unit of heat,** so that we can speak of its amount in a definite way. The amount of heat needed to heat a **pound** of water through **one degree,** Fahrenheit, as from 60° to 61° F., is called a **British Thermal Unit** (B. T. U.). The amount of heat needed to heat **one gram** of water through one **Centigrade degree,** as from 15° C. to 16° C., is called a **calorie** (kăl′ō-rĭ). There are 252 calories in one British Thermal Unit.

If you have some cold water in a washbowl, and wish to warm it, you add a certain amount of hot water. Is there any way of knowing just how much hot water to use in order to heat the cold water to any given temperature? If you mix a pound of water at 212° F. with a pound of water at 32° F., what will the result be? You will have 2 pounds of water at a temperature halfway between 32° and 212°, or at 122° F. The hot water loses 90 B. T. U., and the cold water gains the same amount.

Similarly, 1 g. of water at 100° C. mixed with 1 g. at 0° C., will give 2 g. at 50° C.; and 2 g. at 0° C. mixed with 1 g. at 100° C. will give 3 g. at $33\frac{1}{3}$° C., and so on. The cold water gains the heat which the hot water loses.

In order to carry out experiments on the amount of heat in a body, we use an instrument called a **calorimeter** (kăl′ō-rim′ē-tẽr). A simple form of it is a metal vessel with polished sides (Fig. 44). A covering of wool felt (a nonconductor of heat) prevents the air from taking heat away from the vessel, or adding heat to it.

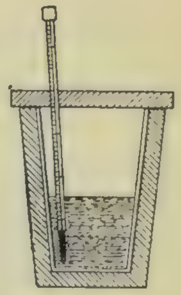


Fig. 44. A simple calorimeter.

The calorimeter helps us to get many important facts. A factory using a large amount of coal needs to test different kinds of coal to learn which one gives the most heat for the least money. The worker in domestic science wants to know how much heat different kinds of food, such as butter, potatoes, fish, or bread, will give out in our bodies. In this way we can get an idea of the values of these foods. We find the heating value of a coal by **burning** a sample in a calorimeter; we do the same for a food. Such a calorimeter (Fig. 45) is more complicated than the simple calorimeter, but the principle of its working is the same. A sample of the fuel or food is burned in an enclosed space containing compressed oxygen, or some oxidizing substance (see § 27). The heat produced in the burning is given up to a known weight of water in the vessel surrounding the combustion chamber. From the weight of water used, and its increase in temperature, the calories of heat given off in the burning can be calculated. What is meant by a "100-calorie" portion of meat?

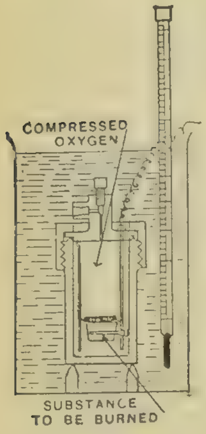


Fig. 45. A bomb calorimeter. By means of it we find the calories of heat given off when we oxidize a definite weight.

52. How a Refrigerator Works.— Why is food kept in a refrigerator (Fig. 46)? To keep it cold, and therefore to prevent it from "spoiling" (see § 30). What cools the air of the refrigerator? The ice. What becomes of the ice? It melts. What causes it to melt? Of course, the ice melts because of heat that is given to it by the refrigerator itself, by the air of the refrigerator, and by the food placed in it. As these **give their heat** to the ice, they themselves are cooled.

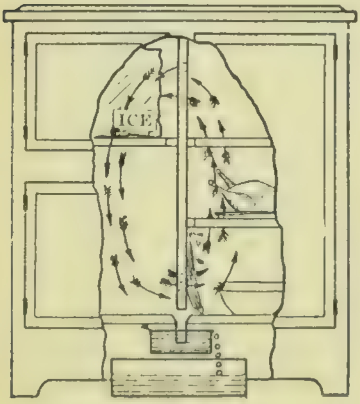


FIG. 46.
Food in a refrigerator gives off its heat to air and to ice, and so becomes cooled. The arrows show convection currents of air. A "trap" at the bottom, filled with waste water, prevents the cold air at the bottom from falling out.

It takes a definite amount of heat to melt a given quantity of ice. The amount of heat required to change 1 g. of ice at 0° C. into water at 0° C. is **79 calories.** What becomes of this heat? It does not raise the temperature of the ice. It changes the crystals of solid water into liquid water. How hot would 1 g. of water at 0° C. become if 79 calories were added to it? Review §§ 44 and 51. What becomes of the heat that is added to **boiling** water without raising its temperature? This amount is also definite: **540 calories** are required to convert 1 g. of water at 100° C. into steam at the same temperature. How many grams of liquid water could be heated from 0° C. to 100° C. by means of 540 calories?

We often speak as though we added "cold" to food in a refrigerator. Does ice conduct or radiate "cold"? Is not **cooling** a body simply **taking heat** from it? The food is cooler because it gives some of its heat to the ice. If we put enough chipped ice into water, the water is cooled to the temperature of melting ice, that is, to 0° C. The amount of ice we need to add depends upon the weight and temperature of the water.

The temperature at which water freezes (in the presence of ice) is the same as the temperature at which ice melts. So we put a thermometer into **melting ice** (see § 47) to get the "freezing point" of the thermometer. The temperature of the ice and of the water in contact with it remains at 0° C. until all the ice is melted.

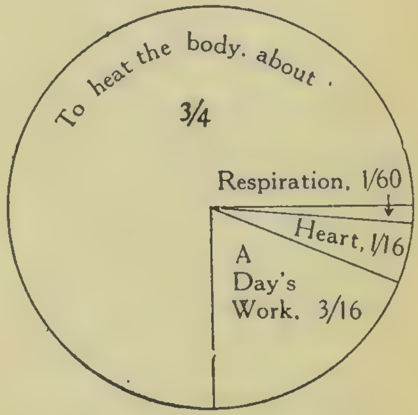


FIG. 47.
Distribution of heat obtained from food.

53. How the Body Keeps Its Heat.

—When you put on clothing in a cold room, does the clothing make you warm? Does not the clothing have the same temperature as the room? Clothing keeps us warm by **preventing** the heat of the body **from escaping.** The best clothing for the purpose is made of **nonconducting** materials, such as **wool.** Wool is the natural covering of the sheep, an animal that lives through cold winters in the open. Wool is a nonconductor largely because of the **air** it encloses. The feathers of birds keep the birds warm, not only because the feathers are nonconductors, but also because they hold **air.** Fur acts in the same way. Why do birds fluff out their feathers on a cold day? Because in this way they imprison a great deal of **air** in

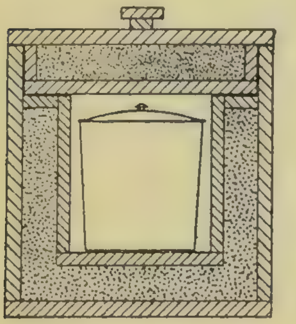


FIG. 48.
A "fireless cooker" is a box made of nonconducting material which does not allow the heat to escape from cooking food.

their feathers; this air is the real nonconductor that prevents the body heat from escaping. For the same reason it is easier for us to keep warm in moderately loose winter clothing than in tightly fitting clothing. Is there any reason why a man who works in a very **hot** place, say, a fireman, should wear woolen clothing?

54. How the Body is Kept Cool.— It is as important to prevent the body from becoming too hot as from becoming too cold. Wet your hands with water having the temperature of the room, and wave them rapidly until the water evaporates. Do they feel warmer, or colder? Try the following also: put some ether or gasoline on the skin and blow over it rapidly. Is the skin heated, or cooled? These experiments show us that when liquids evaporate they **take heat** from objects in contact with them, and thus cool the objects. This is what perspiration does for our bodies. It is constantly being given off by the skin, even when we do not know it. When we exercise violently, it is formed more rapidly than it can evaporate; we then have *noticeable* perspiration, or **sweating.** But whether we notice the perspiration or not, its evaporation is taking heat from the body, just as a boiling liquid is taking heat from a fire.

In tropical countries a jar of porous earthenware is used for the cooling of drinking water. As some of the water oozes through the walls of the jar, it evaporates, and by so doing takes heat away from the water left in the jar.

An **iceless refrigerator** (Fig. 49) can be made of a wooden frame covered with heavy canton flannel. On the top of the frame is a pan of water with strips of wet flannel conducting water (see **capillarity,** § 119, and **siphon,** § 14) from the pan to the flannel covering.

The evaporation of the water from the flannel absorbs heat from the air and food inside the refrigerator, and thus cools them. Ought the water jar and the iceless refrigerator to be placed in the sun, or in the shade? In a quiet place, or where a breeze is blowing? Does perspiration evaporate more rapidly when the air is moving, or when it is still?

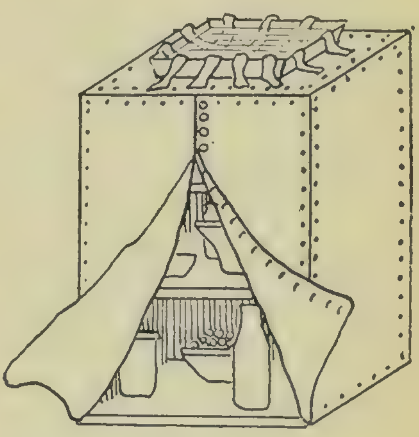


FIG. 49.
An iceless refrigerator, cooled by evaporating water.

55. Summary.— Heating the house means heating the **air** of the house.

Kindling a fire means raising the temperature of its combustible substances to their ignition temperatures.

The **fireplace** is both an ornament and a means of ventilation.

A **stove** is a surrounded fire, with its air supply and flue controlled by dampers.

Gas stoves are Bunsen burners.

Gasoline must be thought of as an inflammable gas.

Both **hot-air furnaces** and refrigerators work because of convection currents of air.

Heat is **distributed** in three ways: (1) by **conduction**; (2) by **radiation**; (3) by **convection.**

Hot-water heaters work because of convection currents of water.

Steam radiators give off heat because of the condensation of steam to water.

Electric heaters contain wires or strips in which the electric current is changed to heat.

Temperature is the **degree** of heat, not the quantity.

Thermometers make use of the expansion and contraction of liquids in glass tubes.

Heat is the energy of motion of the molecules. Its **amount** is measured in British Thermal Units or **calories.**

In a **refrigerator** the heat needed to melt ice is taken from the objects cooled.

We retain our body heat by means of **nonconducting** clothing.

The body is kept from retaining too much heat by means of **evaporating** water: the perspiration.

In an **iceless refrigerator** the heat needed for the evaporation of water is taken from food, and cools it.

56. Exercises.— 1. Which feels colder, the metal knob, or the wood of the door? Which is really the colder? Which would feel hotter, if both were at 100° F.? Tell why.

2. Which feel colder, your woolen mittens, or your rubbers? A woolen rug, or the polished floor?

3. Have you ever noticed telegraph or telephone wires sag in summer, while they are taut in winter? The reason?

4. If you try to heat water in a thick glass or bottle, the vessel usually breaks, while a thin glass beaker does not. Tell why.

5. The body temperature is 98.6° F.; what is it on the Centigrade scale? What is the Fahrenheit temperature for 20° C.?

6. Are cotton and linen clothing better for winter, or for summer?

7. Is it correct to say that storm windows and weather strips "keep out the cold"?

8. Describe a fireless cooker, and tell how it works. Is it also a "heatless" cooker? What is the source of the heat?

9. Describe a Thermos bottle, and tell how it works.

10. Why does sprinkling a lawn in hot weather cool the air?

11. Name as many as possible of the sources from which we get heat. Which are the most important?

12. If the gas of a gas stove burns with a smoky flame, what is the trouble? What steps would you take to correct it?

57. Projects.—1. Examine a steam-heating plant that supplies heat to buildings or rooms at a considerable distance, and describe it, including the distance the steam is carried and the method used to protect the pipes, so that the steam may not lose its heat (condense) too soon.

2. Add to a Fahrenheit house thermometer a strip of paper showing the corresponding Centigrade readings.

3. Find the temperature of the water in an automobile radiator before starting the car, and then at the end of each mile.

4. Determine the change in temperature for one hour, at intervals of 5 minutes, of a pint of hot water, say at 80° C., in each of the following vessels: (a) Thermos bottle; (b) a deep cup or tin can wrapped closely in woolen cloth; (c) a similar dish wrapped in cotton cloth; (d) a similar dish, unwrapped.

5. Make a "fireless cooker" out of two covered pails of different sizes, filling the space between the pails with nonconducting material, such as shredded paper. Compare the rate at which a pint of hot water in the inner pail becomes cold with the rate in an unprotected pail.

6. Determine the effect of an air current (produced by an electric fan, or a palm-leaf fan) upon two thermometers, the bulb of one of them being wrapped in a bit of absorbent cotton wet with gasoline or carbona.

7. Determine whether a piece of telephone wire about 20 ft. long is longer, or shorter, and how much, in a warm room than out of doors on a cold day.

8. By means of a thermometer find the temperature of a number of objects on the floor of a room, including that of the floor itself.

9. Kindle a fire before the class, without matches, by the methods used by the Camp Fire Girls or the Boy Scouts.

10. Test the rate of melting of ice cream in dishes of different materials, including cardboard.

11. Test the rate of heating of wooden, iron, plated, and solid-silver spoons put at the same time into a cup of boiling hot water.

12. Take the temperature of a room, heated by hot water or steam, at several places on the floor, at the ceiling, and halfway between, and compare results.

58. References.— ALLEN: *Mechanical Devices for the Home.* BARBER: *First Course in General Science.* LYNDE: *Physics of the Household.* MILLIKAN AND GALE: *A First Course in Physics.* TOWER, SMITH, TURTON, AND COPE: *Physics.*

CHAPTER V

CARBON DIOXIDE

59. Why Wood is Charred by Heating.— If you light a match or splinter, and then extinguish the flame, the "burnt" end is no longer wood, but **charcoal.** Charcoal is a form of **carbon.** If we heat wood in a deep dish, such as a test tube or an iron box (Fig. 50), and apply a burning match to the open end, we find that a gas is escaping and can be set on fire. When we are through heating, there will remain a black mass of charcoal, much lighter than the wood we used. If we heat soft coal in the same way, we obtain a combustible gas, with a mass of **coke** in the dish (see § 200).

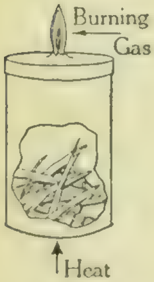


FIG. 50.
The "tin" box has a cover with a nail hole in it. When the box is heated, the wood is charred and gives off a combustible gas.

Nearly all materials obtained from plants and animals behave like wood when heated: part of the substance *chars*, or turns to carbon, while the rest escapes as gas or vapor. We see this when sugar or milk is spilled upon a hot stove. Charcoal is made on a large scale (Fig. 51) by set-

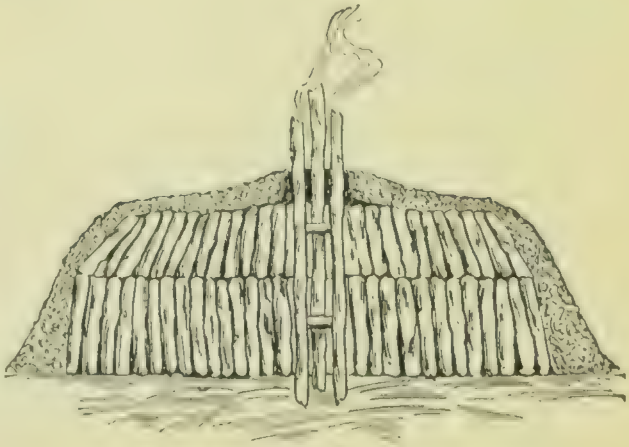


FIG. 51.
We make charcoal on a large scale by letting a slow fire burn in covered heaps of wood.

ting afire great heaps of wood. The wood is covered with sod, but small openings are left to allow a little air to enter and gases to escape. The part of the wood that burns furnishes the heat needed to char the wood which is near it, just as is the case in the burning of a match.

Coal is the material which remained when wood and other plant substances decayed slowly under layers of mud and sand. The covering materials caused great pressure, and kept out the air.

60. What is Formed When Carbon Burns?— If wood, coal, or paper is entirely burned up, only ashes remain, of course. But if it is only charred, there is left carbon, which can be burned in air or oxygen. As we saw in § 29, Chapter III, if a piece of charcoal is held in a flame, it is set on fire and burns with a **glow.** If then we hold the glowing charcoal in a bottle of **oxygen**, the charcoal burns with a brilliant light. After a while the burning stops; why? If now we put some **limewater** into the bottle, the limewater becomes white, or **milky.** This milky appearance is caused by floating, white particles of calcium carbonate formed by the uniting of carbon dioxide with the lime of the limewater. The carbon dioxide was formed by the uniting of the carbon of the charcoal with the oxygen. In the same way iron burns in oxygen to form iron oxide, and phosphorus to form phosphorus oxide. The behavior of limewater serves as a **test** for carbon dioxide, because it tells us whether a given gas is carbon dioxide, or not. In a similar way a glowing splinter is used as a test for oxygen (see § 29).

If we burn such substances as wood, coal, paper, or wax in a bottle of air or oxygen, and make the limewater test, we find that carbon dioxide is formed in each case. Even the **diamond** and the black lead, or **graphite,** of our lead pencils can be burned in oxygen. The product is carbon dioxide. Therefore diamond and graphite are, after all, only forms of carbon.

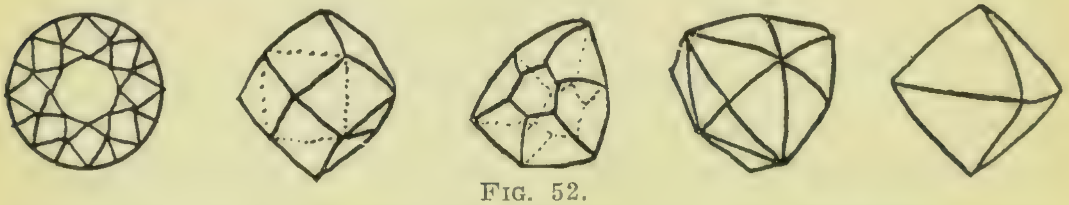
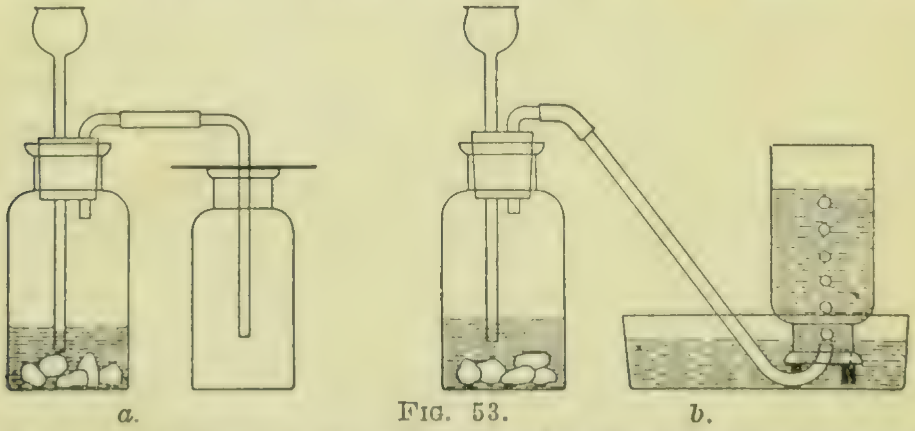


FIG. 52.

Crystalline forms of the diamond. The figure on the left shows a "cut" diamond; the others represent natural forms. *(After Farrington.)*

61. Preparation of Carbon Dioxide.— One way of preparing carbon dioxide is, as we have seen, to burn carbon, or substances containing it, in vessels of air or oxygen. When the substances cease burning, the bottles contain some carbon dioxide, but also unused air or oxygen. To prepare carbon dioxide free from other gases we use **marble** and a dilute **acid** (Fig. 53), such as dilute hydrochloric acid or vinegar. The liquid froths, or effervesces, because tiny bubbles of gas rise through it. In the same way we have whitecaps on lakes or the ocean, because air bubbles rise through the waves.



a. FIG. 53. *b.*

a. Carbon dioxide may be collected under air, since it falls to the bottom of the bottle. *b.* The gas may also be collected over water, like oxygen.

Carbon dioxide may be collected **over water,** as oxygen is, or, since it is 1½ times as heavy as air, it may be allowed to pour out of the delivery tube of the generating bottle into a bottle of air. In a short time all the air will be replaced by carbon dioxide. We can prove this by putting a burning match into the bottle; the match will be extinguished. Carbon dioxide may be poured like water from one vessel to another (Fig. 54).

We can prepare carbon dioxide from baking soda or washing soda, with vinegar or lemon juice in place of hydrochloric acid.

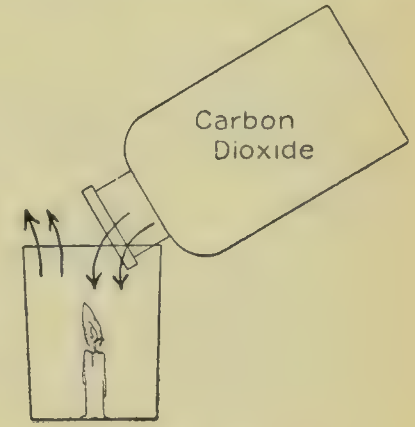


FIG. 54.
Pouring carbon dioxide like water.

62. What is Carbon Dioxide Like?— Carbon dioxide is colorless, like air and oxygen. It does not allow burning to go on. Instead, it puts out a burning match or candle *instantly*. Compare this with the action of a bottle of air. If we bring limewater and carbon dioxide together, **calcium carbonate** is formed; this substance exists in nature as marble and limestone.

If we put into a pop bottle about a tablespoonful of baking soda, enough water to half fill the bottle, and 3 or 4 teaspoonfuls of an acid such as lemon juice, vinegar, or very dilute hydrochloric acid, we shall have a mixture that will produce carbon dioxide. If we stopper the bottle at once, the frothing which takes place at first will stop almost entirely. The carbon dioxide cannot escape, so it becomes more and more compressed as more and more of it is formed. In this compressed state the gas dissolves more readily in the liquid. But when we open the bottle, and thus release the pressure, there is a strong frothing as the carbon dioxide escapes from the liquid.

Why is water containing compressed carbon dioxide called **soda water?**

Beneath the earth's surface the water and carbon dioxide are under greater pressure than at the surface, because of the rock above them. Hence more carbon dioxide can dissolve. When water charged with carbon dioxide reaches the surface, as it does in some springs, it effervesces like soda water. We call such springs "carbonated" springs.

63. Carbon Dioxide as a Fire Extinguisher.— Since carbon dioxide does not allow burning to go on, it can be used to advantage to put out fires. This is especially true if the fire is small, for the carbon dioxide does not damage the objects which do not burn, while water does. It cannot be used efficiently for large fires, because it cannot be produced in large enough amounts.

In the ordinary "chemical" fire extinguisher, such as is used to protect a school building or factory (Fig. 55), the carbon dioxide is formed by the action between baking soda and an acid. The soda is dissolved in water, and the solution is kept in a strong metal tank. A bottle of sulphuric acid is fastened in the upper part of the tank. When the tank is turned upside down, the acid is spilled out of the bottle and acts with the soda, forming carbon dioxide. The pressure of the carbon dioxide forces out some of the water and carbon dioxide; these put out the fire. The carbon dioxide, though invisible, covers the burning body like a blanket, and keeps oxygen away.

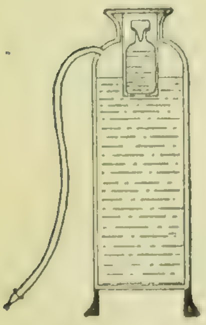


Fig. 55. A carbon dioxide fire extinguisher, containing a solution of soda and a bottle of sulphuric acid.

A mixture of baking soda and dry sawdust is also used to put out fires, especially gasoline fires. The heat of the fire causes the soda to give off carbon dioxide.

64. How Carbon Dioxide Gets into the Air.— If you set a dish of limewater in the air of a room, it soon becomes covered with a white crust, or scum. This is the same solid that makes limewater milky: **calcium carbonate** (see § 60), and the fact that it is formed shows that there is carbon dioxide in the air. How does carbon dioxide get into the air? We have seen that when charcoal or any other form of carbon burns in oxygen, carbon dioxide is the product. It is also formed when wood, coal, paper, a candle, kerosene, gasoline, or any other substance that contains carbon is burned in air or oxygen. Hence an enormous amount of the gas gets into the air from ordinary **burning.**

Carbon dioxide gets into the air not only from burning, but also from the breathing, or **respiration,** of animals and plants. If you blow your own breath through limewater (Fig. 56), you will see that you are exhaling carbon dioxide, and that you must be adding it to the air by your breathing.

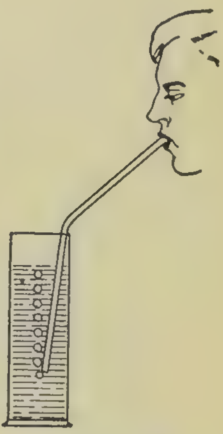


FIG. 56. The limewater becomes "milky" because it acts with the carbon dioxide in your breath to form solid particles of calcium carbonate.

Carbon dioxide gets into the air in enormous amounts by a **third** process: the natural **decay** of wood, leaves, and fruit, and the bodies of dead animals. The carbon of the decaying substance is changed chiefly to carbon dioxide, much as if the substance had actually been burned.

There is another common natural process by which great quantities of carbon dioxide are formed: the **fermentation** of fruit juices. When juices like those of the apple and grape stand exposed to the air, they "work," or ferment. If we examine the fermenting juice, we find that it is warmer than the surrounding air, that a gas comes off from it (carbon dioxide) and that the sweet taste of the juice is changed to that of alcohol. The cause of this fermentation is the **yeast** plant. Yeast may not look much like a plant, but it is. The **spores,** or seedlike bodies, of wild yeast fall into the fruit juice, and sprout, and in their growth change the sugar of the juice into alcohol and carbon dioxide. When **bread** is made, carbon dioxide is formed by the action of yeast upon sugar and flour, and causes the dough to **rise.** The alcohol and carbon dioxide are largely driven off in the baking. In what foods is baking powder used to give lightness?

65. How is Carbon Dioxide Removed from the Air?—Why does not the carbon dioxide given off by living creatures, by all burning, and by all decay become so abundant that fires will no longer burn and animals and plants will not be able to live? We can get the answer to this question by letting a green plant (Fig. 57), in the presence of sunlight, act upon water containing carbon dioxide.

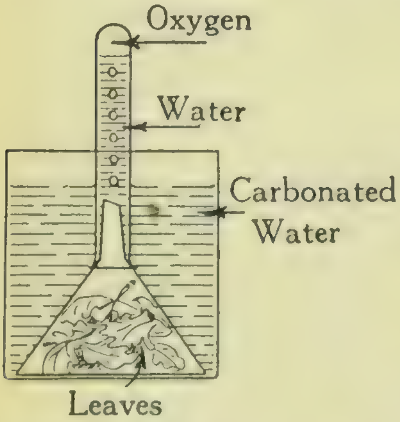


FIG. 57.
Green plants, in the presence of sunlight, act upon water containing carbon dioxide and set oxygen free.

Prepare some *carbonated water* (see § 62) by passing carbon dioxide, made as in § 61, into a large, small-mouthed bottle half full of water. The mouth of the bottle is to be upward, so that the air will be displaced by carbon dioxide. Then stopper the bottle and shake the gas and water vigorously together.

Into a deep glass jar (battery jar) place, upside down, a large funnel filled with spinach or parsley; then almost fill the jar with carbonated water. The funnel stem must be entirely under water. Now fill a test tube with water, close its mouth with your thumb, and invert it carefully over the funnel stem. Set the apparatus in bright sunlight for an hour or two.

Bubbles of gas rise into the test tube. When enough has been collected, remove the test tube from the funnel, close its mouth with your thumb, and turn the tube right side up. Test the gas with a glowing splinter. It is **oxygen,** set free from the carbon dioxide by the plant and the sunlight (see § 203).

So the answer to the question as to how carbon dioxide is removed from the air is that **green plants** remove it, and give back oxygen in its place.

66. Relation of Plants to Animals.— Do plants help animals? As you think of it, you will realize that animals as a class feed upon plants and the materials which plants prepare. From the last paragraph we have learned that plants help animals in another way: they prepare and purify the air for the use of animals. In their **respiration** (see § 71) animals pour into the air enormous quantities of carbon dioxide and use up oxygen, while green plants use up the carbon dioxide and return oxygen in its place. The carbon of the carbon dioxide they build up into such substances as starch, sugar, and cellulose (see Chap. XVIII).

This careful balance between the action of plants and of animals is one of the most interesting facts that man has discovered. It may be studied in an aquarium. If small animals, such as goldfish, are placed in an aquarium, and the right amount of water plants is added, the water will not become stale, for the plants will use up the carbon dioxide that is given off by the animals, and will return the oxygen of the carbon dioxide to the animals for their use.

67. Summary.— When heated, most substances containing carbon are **charred,** or turned to charcoal.

Coal is the residue left by plants of past ages.

When **carbon,** or substances containing it, burn in air or oxygen, **carbon dioxide** is formed.

Diamond and **graphite** are forms of carbon.

Carbon dioxide is prepared most easily by the action between marble or soda and a dilute acid. It is heavier than air, and may be poured like water.

Carbon dioxide does not burn or allow burning to go on. It is therefore used as a **fire extinguisher.**

Carbon dioxide **dissolves** in large amount in water under pressure. **Soda water** is a form of carbonated water.

The **test** for carbon dioxide is its action with limewater to form a deposit of **calcium carbonate**; as a result the limewater becomes **milky.**

Carbon dioxide **gets into the air** from all ordinary burning, from the **respiration** of animals and plants, from **decay,** and from the **fermentation** of fruit juices by yeast.

Carbon dioxide is **removed** from air by the action of green plants under the influence of sunlight. As a result **oxygen is returned** to the air for the use of animals.

68. Exercises.— 1. Why does wood burn with a flame, while charcoal does not? Do you think a diamond would burn with a flame? Why?

2. What fuel does a blacksmith use for his fire? Why does he use bellows?

3. Does wood charcoal leave ashes when burned? Is wood charcoal pure carbon? Would sugar charcoal leave ashes?

4. Is it possible that coal is being formed now? Where? What is peat?

5. In what sense does coal contain the stored energy of the sun?

6. Does kerosene burn with a smoky or a colorless flame? Alcohol? How could you prove that alcohol contains carbon, and forms carbon dioxide when it burns?

7. What is the danger of sleeping in a room in which there is a stove?

8. When baking soda is put with tomatoes, frothing takes place. What gas is being formed? Why?

9. Would a carbon dioxide fire extinguisher be more efficient for a fire near the floor, or near the ceiling? Why?

10. If a candle is put into an old well, and is extinguished by the air of the well, what gas is probably present? Is it safe for a man to enter such a well?

11. In entering certain caves, a dog is often overcome by the air, while a man is not. Explain why.

69. Projects.— 1. Devise a way of finding out, by trial, which causes limewater to become milky sooner: the air of a crowded schoolroom or the air out of doors.

2. Remove the limestone from a long, slender bone, so that the organic material which remains may be **tied in a knot.** SUGGESTION: Soak the bone in dilute hydrochloric acid for a day or two; then rinse it in water.

3. Burn a bone, and prove that the ashes contain the limestone of the bone. SUGGESTION: Treat the ashes with dilute hydrochloric acid, and test the gas formed.

4. Determine if wood ashes give carbon dioxide when treated with an acid.

5. Find out whether, or not, the juice of oranges, lemons, or grapefruit causes baking soda to give off carbon dioxide.

6. Test the air of a well or cistern for the presence of an unusual amount of carbon dioxide.

7. Determine if a paper bag filled with carbon dioxide weighs more than when filled with air.

8. Devise apparatus to show that gaseous carbon dioxide can be poured like water.

9. Determine if the gas given off by pop, ginger ale, and soda water is carbon dioxide.

10. Prove that carbon dioxide is formed in the rising of bread. SUGGESTION: Set the bread sponge in a loosely covered bottle.

11. Set up an aquarium containing water plants, and then put a goldfish, some tadpoles, and water snails into it.

12. Show the class that a combustible gas is formed when soft coal or wood is heated. See § 59.

13. By an experiment prove to the class what gas is formed when baking powder is treated with water.

70. References.— CONN: *Bacteria, Yeasts, and Molds in the Home.* HESSLER AND SMITH: *Essentials of Chemistry.* SMITH AND JEWETT: *Introduction to the Study of Science.*

CHAPTER VI

THE AIR WE BREATHE

71. Why We Breathe.— The act which we call **breathing** is the taking of air into the lungs (inhaling), and then expelling the used air from the lungs (exhaling). It has been found that while the air that rushes into the lungs is more than one-fifth (by volume) oxygen and contains very little carbon dioxide, the air that leaves the lungs has lost a considerable part of its oxygen and has gained carbon dioxide in its place. Hence in supporting life, as in supporting fire, air loses oxygen and gains carbon dioxide. Breathing, then, is for the purpose of taking oxygen into the body and removing carbon dioxide from the body. The oxygen we take in does not stop in the lungs, but passes through the walls of the lungs into the blood vessels. The blood carries it to all parts of the body. The whole process by which oxygen gets to the cells of the body is called **respiration.** A man of average size takes in about 350 cubic feet (10 cubic meters) of air in a day. How much oxygen does this contain? See § 24.

Why do we need so much oxygen? **One** purpose of respiration is to **oxidize the food** we eat; a **second** purpose is to get the oxygen to combine with the materials of the body that are constantly wearing out, and to oxidize them to substances that the body can get rid of.

Digested food, like oxygen, is carried by the blood to all parts of the body. The oxidation of our food, and of the worn-out materials of the body, is a change somewhat like the burning of coal in a stove. It is not an actual fire, but it produces **heat**; this heat keeps the bodies of animals warm (see § 50). It is by the oxidation of our food that we get the power to move and to do work. In man the normal temperature is 98.6° Fahrenheit, winter and summer. After accidents and in certain diseases the body is not able to get oxygen rapidly enough from the air; hence a **pulmotor,** supplying pure oxygen, is used.

Water animals need oxygen to oxidize their food and worn-out tissues, just as land animals do. Such creatures as fishes, clams, tadpoles, and lobsters depend upon the oxygen dissolved in the water in which they live. In their **gills** the same exchange of carbon dioxide for oxygen takes place as in the lungs of higher animals.

72. Need of Ventilation.— Ventilation means the supplying of fresh air to a room and the taking out of used, foul air. Our modern houses give us shelter, warmth, and many comforts, but they usually rob us of air. When houses were built of logs, and were heated by open fireplaces, men did not need to think much about ventilation; for the large opening of the fireplace carried off a great deal of air from the room, and to take the place of this air there was a fresh supply rushing in through cracks around doors and windows, and even through chinks in the walls. But as men have built tighter walls, used weather strips and storm windows in winter, and installed stoves, furnaces, and steam and hot-water heaters, in place of the fireplace, **natural ventilation** has largely disappeared. Doctors know how common it is for people who are healthy enough in warm weather, when they keep doors and windows open, to have colds and other troubles of the nose, throat, and lungs almost as soon as cold weather comes on, and their houses are tightly closed. When we "keep out the cold" in this way, we shut off our supply of fresh air and invite the attack of disease.

It has been estimated that in **one hour** a healthy man makes about 4,000 cubic feet of air unfit to breathe. That is to say, if one man were put into an air-tight room 20 feet square and 10 feet high, he would make the air bad in one hour. Of course rooms are not air-tight, and much fresh air gets in around doors and windows even when we do not try to ventilate. Schoolrooms have a large number of persons in a small space and need special care. According to a Massachusetts law each pupil should get at least 1800 cubic feet of air every hour. If a person coming in from out of doors notices that the room has an odor, the air of that room has been breathed too often. Work in such a room is probably dull and slow.

73. Methods of Ventilation.— Carry out this **experiment** to learn how our houses are ventilated **naturally**:

Open the door between a warm room and a cold one, and hold a lighted candle or match near the top of the doorway. You will find that the flame is blown from the warm room toward the colder one. Now hold the flame near the bottom of the doorway; the flame is blown from the colder room toward the warmer one. The flame shows how the invisible air currents are moving. Cold air flows in at the bottom of the room to take the place of the warmer air, which rises and flows out at the top. The reason for this behavior is that when air is warmed it expands so that a given volume of warm air weighs less than the same volume of cold air (see § 41). You have seen this fact put to use in the hot-air balloons that are sent up on the Fourth of July and other holidays.

Natural ventilation is, then, the method which depends upon the entrance of cold air at the bottom of a room and the passing out of warm air at the top of the room. When does natural ventilation work better, in summer, when the temperature inside and that outside are nearly the same, or in winter, when there is such a great difference between them? Are not weather strips, storm doors, and storm windows really used to *prevent* ventilation and to hold the warm air inside the house?

In large buildings natural ventilation cannot be depended upon, and *forced ventilation* must be used. The heating and ventilating can thus be done together. One method is to force fresh air currents over steam coils by means of rotating fans in the basement. After the air has been heated, it is forced into the rooms of the building. The used air escapes through openings in the walls or ceiling. Another method of forced ventilation is to remove the impure air by means of rotating fans and to bring in warm, fresh air through small holes near the floor. Find out how your school building is warmed and ventilated.

In a modern, large auditorium the whole body of air may be changed every 10 or 15 minutes. The air may be blown through a **spray of water**; in this way it is made moist (see § 76), and dust and bacteria are washed out. The ventilation system may also be used to cool buildings in summer, if the fresh air is first passed over ice or pipes of cold brine (see § 96).

74. How to Ventilate a Room.— If a schoolroom depends upon natural ventilation, shall we have several windows each open a little, or one wide open? We shall find that a large window opening gives stray air currents (drafts), while several small openings will give just as much circulation, but no person will feel a draft. The openings should be on the side of the building opposite the wind.

When a stove is used to heat a room, air currents are made by the stove (see § 41). This is especially true if a "drum" is used. The cold air comes along the floor from the farthest corners of the room, is heated, rises, and flows back to the corners from which it came. In this way the room is heated and ventilated more evenly.

We must remember that while stoves and hot-air furnaces provide a **little** ventilation, since fresh air from outside **must** come in to take the place of the air that goes through the stove, hot-water and steam heating systems **of themselves** give no ventilation whatever.

Another important thing to know about the ventilation of a room is that air becomes unfit to breathe, not so much because it contains impurities, as because it is **stagnant**. Slightly impure air, if it is moving, is better to breathe than very pure air that is not moving. The greatest need is the free **circulation** of air.

75. How to Ventilate Our Bedrooms.— People forget that **bedrooms** need to be ventilated quite as much as living-rooms. Living-rooms get some fresh air by the opening of doors as we go in and out, but there is little chance for a closed bedroom to get fresh air. So we should have **at least** one window open every night, and we should air the room thoroughly during the day.

The fact that a bedroom is kept cold does not mean that its air is pure; cold air, if not changed often, may be just as unfit to breathe as warm air. An excellent plan, in stormy weather, is to lower the upper sash a few inches. The outside air then enters between the sashes, while the air of the room leaves at the top of the window. Why? If a board with boxed holes (Fig. 58) is put under the lower sash, the air will enter through the holes and pass out between the sashes.

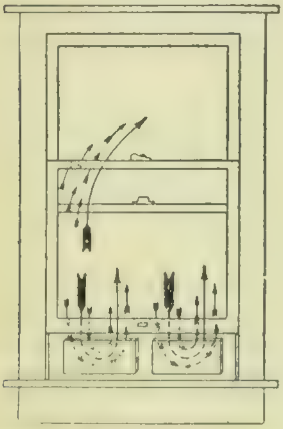


FIG. 58.
A board with boxed holes, set under the lower sash, keeps out rain and snow and yet allows air to enter and leave the room.

Poisonous Gases.—We must remember, too, that gas stoves and kerosene stoves not connected with a chimney are dangerous in closed rooms, both because they use up oxygen and produce carbon dioxide, and also because they may liberate harmful gases (see § 40), which may not be entirely burned up, and so contaminate the air.

Persons who are in a **garage** when an automobile engine is running need to be especially careful to have abundant ventilation; for a very poisonous gas, **carbon monoxide,** also called "coal gas," is formed by the incomplete oxidation of the gasoline. Tunnels through which many automobiles pass need to be ventilated for the same reason.

76. Need of Moisture in Air.— Some days are "sticky," and the perspiration does not evaporate; on such days the air has too much water vapor for our comfort. On other days the moisture of the skin evaporates too rapidly; not only the skin, but the delicate linings of the nose, throat, and lungs become parched and dry. We find air very comfortable, at any given temperature, if it contains between 45 and 60% of the water vapor it can hold at that temperature. It takes up the perspiration properly, and so regulates the heat of the body.

When our houses are closed in winter, and heated to the temperature of summer, the amount of moisture in the air is almost sure to be too small. The reason for this is that the cold air entering a house has its power of holding water vapor increased by warming. The **actual amount** of water vapor is not changed; but the amount present as compared with what the air is **able** to hold is much smaller (see §§ 130 and 131). Such air takes too much moisture from our bodies and makes it easy for us to "catch cold." Authorities say that the moisture in the air of a room should be so great that some of it is deposited, as dew and frost, on the inside of windows in cold weather. Rooms heated by steam or hot water should have the air moistened by pans of water placed near the radiators. Hot-air furnaces usually have pans for water; these should be kept full.

77. Proper Temperature of the Air.— What is the proper temperature of the air of a room? That depends upon several conditions. The amount of **moisture** is one of these. With a proper amount of water vapor in the air, most people feel just as warm at a moderate temperature as in a room which is hotter, but too dry. Then, too, **older people** need a higher temperature than younger people, and **inactive** people than those that are active. About 70° F. is the proper temperature for people who are sitting, but we must remember that the air near the floor is often much colder than that 2 or 3 feet above it. Some people accustom themselves to a temperature of 68° or lower. Most of us have our houses and apartments too warm for our good health.

In public buildings the temperature is usually controlled by a **thermostat** (Fig. 59). A thermometer tells us temperature because the expansion of mercury is greater than that of glass (see § 47). We could also make a thermometer out of two metals which expand different amounts when heated. Thus, if we rivet together a small bar of iron and one of brass, so that the resulting **compound** bar is straight when cold, and then heat the bar, we shall have a **curved** bar; because the brass will expand more than the iron. See § 49, Fig. 43, *b*.

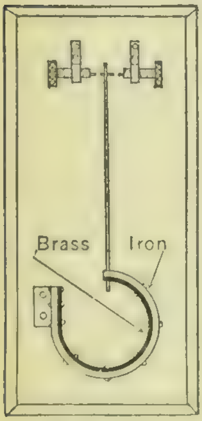


FIG. 59.
A thermostat. If the room becomes too warm, the unequal expansion of the two metals turns the rod to the right; so that it completes an electric circuit which cuts off the heat.

In the thermostat such a bar is made a part of two **electric circuits** (see § 178). It allows the electric current to flow in one circuit when the room becomes too warm, and through the other circuit when the room becomes too cold. There are electromagnets in the circuit; these control the supply of steam or hot water, turning it on or off as needed.

78. How Air is Purified.— Since the atmosphere is all the while receiving impurities from the breathing of animals and plants, from fires, and from decay, why does it not become entirely foul and unfit to breathe? As we think of the question, we see that the impurities are constantly being removed. The **wind** scatters foul air, and mixes it with fresh air from the country, the mountains, and the sea. **Rain** washes out impure gases, dust, smoke, and bacteria, or germs. **Sunlight** destroys many of the bacteria of disease. Other bacteria cause the oxidation of dead materials and destroy them. **Plants** use up the carbon dioxide cast off by animals, and give back oxygen in its place (see §§ 65 and 66).

Soot is an important impurity in city air. Tests made in a certain city in this country showed that about 980 **tons** of soot fell annually upon every square mile.

79. Proper Breathing.— One way in which our study of science can help us is by explaining the importance of fresh air and good methods of breathing. People often speak as though breathing consisted in "sucking" air into the lungs. This is not true. The size of the chest, in which the lungs are placed, is controlled by **muscles.** When the action of these muscles makes the chest larger, the air in the lungs **expands,** and its pressure becomes less than that of the air outside (see § 13). The outer air then rushes into the lungs as it would into any **vacuum,** or space of low pressure, in order to make the air pressure inside and outside the same. When the muscles allow the chest to become smaller once more, the lungs are compressed, and part of their air is expelled.

The air goes through the nose, throat, and windpipe before it enters the lungs. If the nose is healthy, the air is **filtered** from dust and the **germs** that cling to the dust. It is also **warmed.** If we breathe through the **mouth,** the purifying and warming effect of the nose passages is lost, and we are much more likely to have diseases of the throat and lungs. Mouth breathing may be just a bad **habit;** if so, we should overcome the habit at once. It may be caused by a stoppage of the nose by colds or by inflammation of the nose passages. This should be cured. Mouth breathing may also be caused by growths ("adenoids"), which partly close the opening from the nose into the throat. These should be removed by a physician; for they may cause not only mouth breathing and badly formed mouths, but also **deafness.** Children having adenoids often seem to be stupid, when they are really sick.

We can all help to make our breathing what it should be. We should practice **full breathing,** holding our head and shoulders erect, and filling all parts of the lungs, even the lobes near the collar bones, with fresh air. If we must work indoors, we should go out of doors, or to an open window, every little while, and take in deep breaths of fresh air.

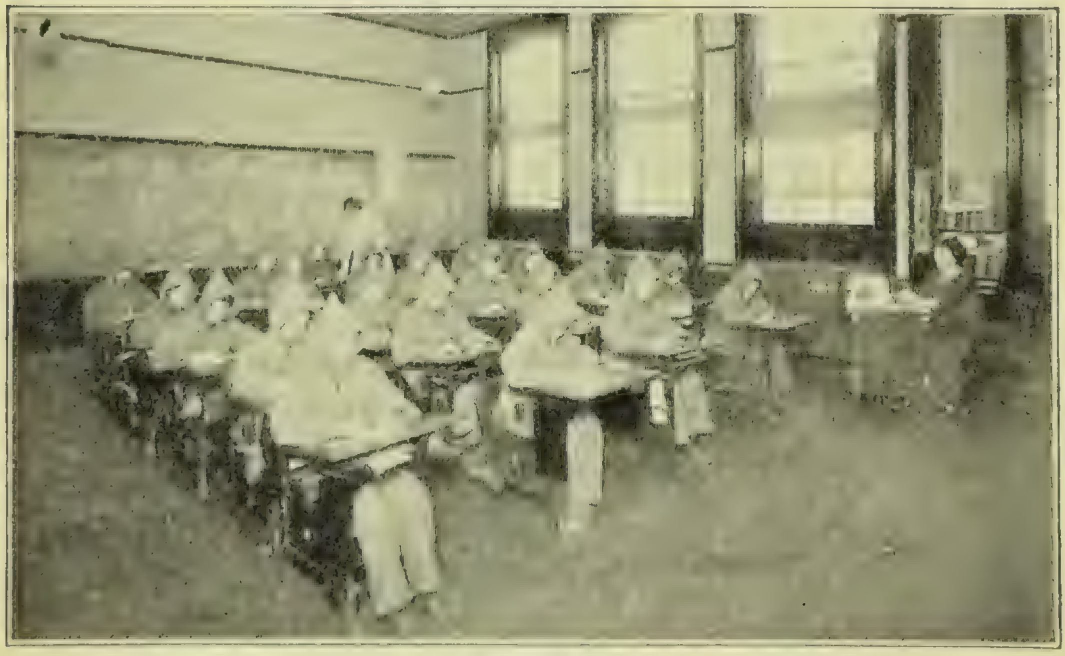


Fig. 60.
An Open-Window Schoolroom, in which undernourished children, clad in "Eskimo" suits, get their lessons. City of Chicago.

80. Fresh Air and Tuberculosis.—Most of us probably know of some one who has, or has had, **tuberculosis,** or consumption. It is called the Great White Plague. Persons suffering from it are now generally given the open-air treatment (Fig. 60); they live in tents, or in the open air, winter and summer, day and night. Of course their clothing must be warm and their food very nourishing. Nearly all who begin the treatment when they are first attacked, are able to cure themselves. Many persons who are healthy guard against sickness by sleeping out of doors, in order that their lungs may have every chance to breathe fresh air.

81. Summary.— **Breathing** is the taking of air into the lungs, and then expelling the used air from the lungs.

Respiration is the process by which oxygen gets to the cells of the body.

We **need oxygen** to oxidize our food and the worn-out materials of the body.

Ventilation is the supplying of fresh air to a room and the removal of used air.

Natural ventilation depends upon **convection currents**, due to the fact that cold air enters at the bottom of a warm room and warm air leaves from the top.

Forced ventilation is usually produced by rotating fans.

Slightly impure air that is **moving** is better than pure air that is **stagnant.**

The air we breathe should have enough **moisture** to prevent too great evaporation from the skin and air passages. A **proper temperature** is also needed.

To breathe properly we should inhale air through the nostrils, and not through the mouth; and we should make a practice of deep, full breathing.

Tuberculosis can usually be cured, in its early stages, by fresh-air treatment.

82. Exercises.— 1. How do **you** ventilate **your** sleeping room? How should it be ventilated?

2. Watch a person who breathes through his mouth; how does such breathing affect his appearance?

3. What should be done for a child that breathes through its mouth?

4. What is the real value of taking breathing exercises?

5. What effect does physical exercise have upon the rate at which you breathe? Is this effect beneficial, or harmful?

6. What should be done for persons who have tuberculosis?

7. Does oiling the roads have any effect upon country air?

8. What effect upon the purity of air has sprinkling a city street?

9. What is the effect of rain upon the purity of air?

10. Have you ever seen any evidence that falling snow removes impurities from the air?

11. Give all the harmful effects of smoke upon the air of a city.

12. Suggest how you could arrange a compound bar of iron and brass (see Fig. 59) so that it would ring a bell to inform the janitor that your room is too cold. Would such an arrangement be of any use in a garage? In a greenhouse?

13. How does a rotating electric fan improve the air of a room, even if the room is closed? How, if the room is open?

83. Projects.— 1. Find out how your schoolroom is ventilated, and report to the class.

2. Prepare a ventilating box for your bedroom (see § 75), and show the box to the class.

3. Prepare a detailed description of the heating system of your house or apartment.

4. Study and describe in detail the provision made in your house for: (a) proper temperature of air; (b) proper moisture of air; (c) movement of air; (d) fresh supplies of air.

5. Devise a plan for securing good ventilation in a basement or cellar.

6. Determine what are the chief agencies that make the air of cities unfit to breathe.

7. Determine what are the chief agencies that are working for pure air in cities.

8. Make a study of "fresh-air" schools, why they are needed, the kind of food and clothing necessary for their pupils, and their results.

9. Make a study of the sleeping porches in your neighborhood, the reasons which the owners give for open-air sleeping, and the results.

10. Make a study of the smoke in the air of your city for one day. Suggestion: Put a large funnel into a bottle, and set them on the roof or in an open place for 24 hours, best on a quiet day. Support them so that they cannot be blown off.

11. Make a study of sweeping the house, and compare broom sweeping, and dusting afterward, with the action of a vacuum cleaner.

12. Prepare a report on the methods of street sweeping in your city, and determine whether they increase, or decrease, the dust in the air.

84. References.— Allen: *Mechanical Devices for the Home.* Barber: *First Course in General Science.* Fisher and Fisk: *How to Live.* Ritchie: *Primer of Sanitation.*

CHAPTER VII

WATER AND HOW WE USE IT

85. Why Do We Need So Much Water?— Do you realize how much our modern life depends upon an abundant supply of water? Of course, we need water for drinking, cooking, and bathing, and for the washing of dishes and clothing. We know also that water is needed for the growing of plants, whether on our lawns, and in our gardens and conservatories, or in the fields and orchards in which our food supply is raised. In the country and in small villages the waste water of the home is simply thrown out upon the ground; but in cities this is not possible, and **sewers** have to be constructed, in which flowing water carries away the waste materials of the street and the household. Water is needed for washing operations not only in the household, but also in **great industries.** Refineries for petroleum and sugar, laundries, tanneries, starch and soap factories, gas works, paper mills, slaughter houses, dye works, and many others need water on an enormous scale. We must not forget another important use of water: it is a **fire extinguisher,** and so protects our cities from destructive fires.

Water in a **solid** state: **ice,** is used in refrigerators to keep our food from spoiling, and, with salt, enables us to have frozen foods, such as ice cream. To the inhabitants of the Arctics ice is a **building material,** and takes the place of wood, stone, and bricks.

Water as a gas: **steam,** is used to drive the world's great engines, and these, in their turn, drive the world's machinery, pull trains across continents, and force ships through the seas.

86. The Water of Nature.— The water we use in our homes comes to us from the city mains or from wells, cisterns or springs (Fig. 61). Cities generally draw their water supply from rivers or lakes. But whatever the apparent source of our water, we know that the real

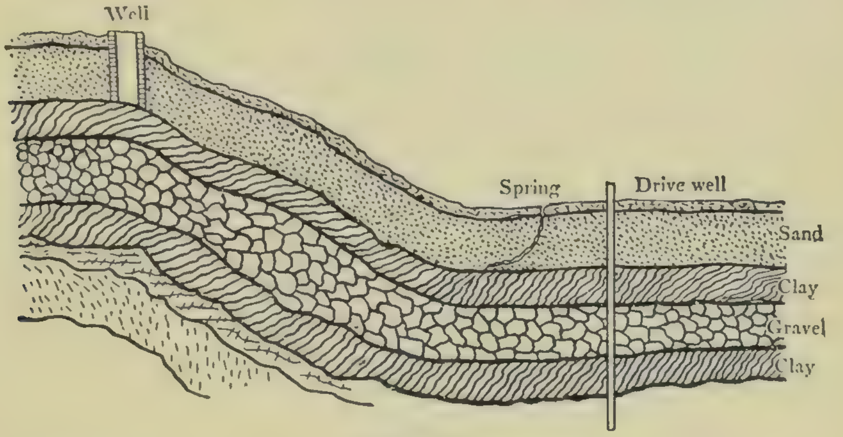


FIG. 61.

Water falling on the higher level soaks through the porous sand until it reaches the clay, which it cannot penetrate. At the bottom of the hill a spring is formed.

source is **rain** and **snow.** The invisible water vapor escapes from teakettles; it also rises from the wet land, the lakes, and the sea. After remaining a part of the atmosphere for a longer or shorter time, it condenses partly to clouds, then condenses more, to rain, hail, and snow, and falls again to the surface of the earth. The water which falls as rain and snow not only **runs off** in streams and **evaporates** as water vapor, but **sinks** into the soil and rocks. As a result we find water everywhere, if only we dig deeply enough, even in the deserts. Water also makes up a great portion of the weight of all **living things**: 50 to 75% of all plant tissues, and 70% of our own bodies. Consult the Appendix, Table XII, and find out how much water there is in such foods as beef, milk, potatoes, eggs, and bread.

We all know how easily sugar, salt, soda, and soap disappear in water. We say that they **dissolve,** and that water is the **solvent.**

Hold a lump of sugar or salt over water in a clear glass, so that the under side of the lump just touches the surface of the water. What is the appearance of the liquid under the lump? This is caused by the sinking of the salt, or sugar, solution before it has mixed with the remainder of the water. Do the same with a lump of copper sulphate (blue vitriol). Are these solutions heavier, or lighter, than water?

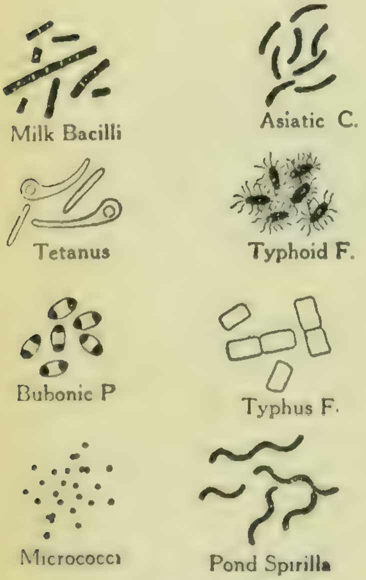


Fig. 62.

As they look when highly magnified. Specimens of the tiny plants called bacteria, bacilli, and micrococci.

Water dissolves most substances to some extent. As a result natural water is never pure. The rain takes up materials from the atmosphere; the water that flows off in streams or through the soil dissolves substances from the soil and the rocks; and both rain and streams take up living creatures, such as **bacteria** (Fig. 62). Rivers and lakes become impure from the sewage, or waste matter, of the cities, factories, and farms upon their banks. The purest natural water is probably obtained by the melting of ice obtained from some source that is pure.

The water of lakes and rivers is usually fresh; the salty substances brought into them are also carried away. The ocean, however, becomes more and more loaded with dissolved substances, because the only outlet of its water is by *evaporation,* which leaves the solids behind. The same is true of Great Salt Lake and the Dead Sea. Where are these? Nearly 2.7% of sea water is common salt. **Mineral waters** contain so much solid matter that it can usually be tasted.

COMPOSITION OF NATURAL WATERS

Source	Grams of Solids in 1000 g. of Water	Cubic Centimeters of Gases in 1000 cu. cm. of Water		
		Nitrogen	Oxygen	Carbon Dioxide
Rain	.029	13.1	6.4	1.3
Rivers and Lakes	.097	15.0	7.4	30.0
Springs	.282	15.8	8.5	1.1
Deep Wells	.438	....	....	....
English Channel	35.25	12.0	6.0	17.0
Mediterranean Sea	40.00	....	....	....
Dead Sea	228.60	....	....	....
Great Salt Lake	230.00	....	....	....
Lake Elton	271.40	....	....	....

87. What Water is Like.— What is the **color** of water? In small amounts it is colorless, but a large amount of it looks blue. The same is true of ice. Is snow ever blue? Drinking water has a **taste,** because of substances dissolved in it (see § 86), but water that has no dissolved material, such as **distilled** water, is tasteless and flat.

At what temperature does water boil? We have already learned (see § 48) that one of the standard marks of the Centigrade thermometer: 100°, is called the "boiling point," while the other standard mark: 0°, is the "freezing point."

The engineer says that "a cubic inch of water gives a cubic foot of steam." If this is true, compare the volume of the steam with that of the water out of which it was formed.

Watch some water as it nears boiling. The first tiny bubbles to escape are chiefly dissolved air. Then there are larger bubbles of steam that start from the bottom, but do not reach the top. These condense and cause the "singing" of the water. Finally the bubbles rise to the surface and burst with force enough to push out the air. The water jumps up and down when it is really boiling. Then, and not until then, will a thermometer show the boiling point of water.

A **cubic foot** of water weighs about 62.5 pounds, and a **cubic centimeter** of it at 4° C. weighs **one gram.** If a flask having a very slender neck is filled with warm water, and then cooled, the water shrinks in volume until its temperature is 4° C. (39° F.); then the water expands again until its temperature is 0° C. This behavior shows that water is **most dense,** or heavy, at 4° C., rather than at 0° C. As a result, the water at the bottom of lakes is not often cooled below 4° C.; for if it becomes colder, it expands, and rises instead of sinking. When water freezes, it expands still more, so that 100 cubic feet of water become 109 cubic feet of ice. Consequently, when we have ice at the top, we have water near 0° C. just under the ice, and water near 4° C. at the bottom. Because of this fact water animals and plants can live through the winter, even in the seas of the frigid zones.

88. Drinking Water.— What is "pure" water? That depends, does it not, upon the **use** we wish to make of it? If we wish to use the water for **drinking,** we are not interested greatly in its dissolved gases and minerals; but we are anxious to find out if it contains decaying matter; for injurious **bacteria** may then be present as well (see § 86). If we take the bacteria of such diseases as typhoid fever and cholera in our drinking water or food, we may "catch" these diseases. If there is any chance that drinking water may be contaminated, we should have it tested. Whether a water is pure or impure cannot be told by its appearance: a dirty-looking water may be safe to drink, while one clear as crystal may contain deadly germs. A shallow well is always a possible source of trouble; for surface filth may be washed into it by rain; and kitchen drains, outbuildings, and barns may be near enough to pollute it (Fig. 63). Ice made from polluted water is also dangerous, for the disease germs are not killed by freezing, but live on in an inactive state. They become active again when they get into our bodies, or into favorable food, such as milk.

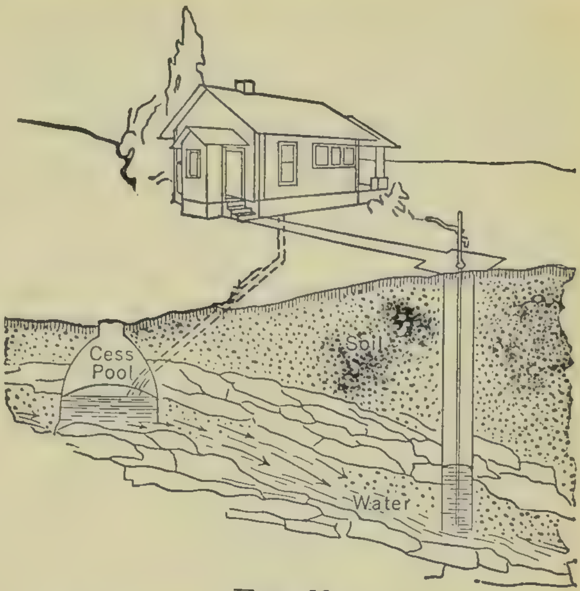


FIG. 63.
How a cesspool, or the drainage from a barn, may pollute well water.

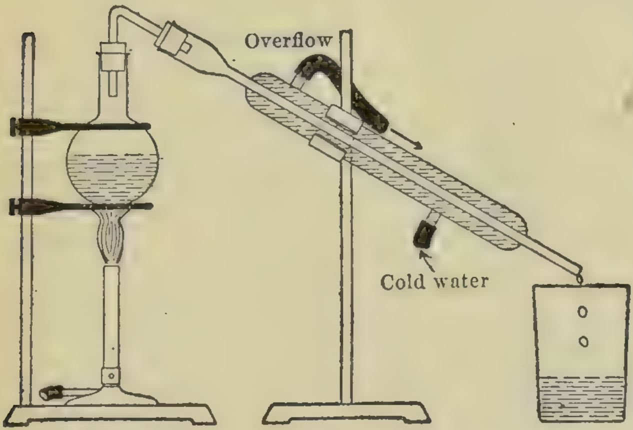


FIG. 64.
How water is distilled on a small scale. The water in the flask is kept boiling, and the steam given off is passed through a condenser surrounded by a jacket through which cold water flows. The cold water enters the jacket at the bottom and overflows at the top.

89. How We Purify Natural Water.— We can purify water: (a) by distillation; (b) by boiling; (c) by filtration; and (d) by the use of chemicals. When the chemist wants pure water, he distils it (Fig. 64). We can get pure drinking water in the same way. The impurities are left behind. In the household we can **boil** the water. This kills the germs. Most of the dissolved solids remain, but the dissolved gases are driven off. The **flat** taste of boiled and distilled water is due chiefly to the absence of dissolved gases, especially **air.** We can improve the taste by shaking the water in a bottle with some air, or by pouring the water in a small stream from one vessel to another. We can also add air to water by filtering the water through porous stone. In all these ways the water may be made to take up again some of the air which it lost when it was distilled or boiled.

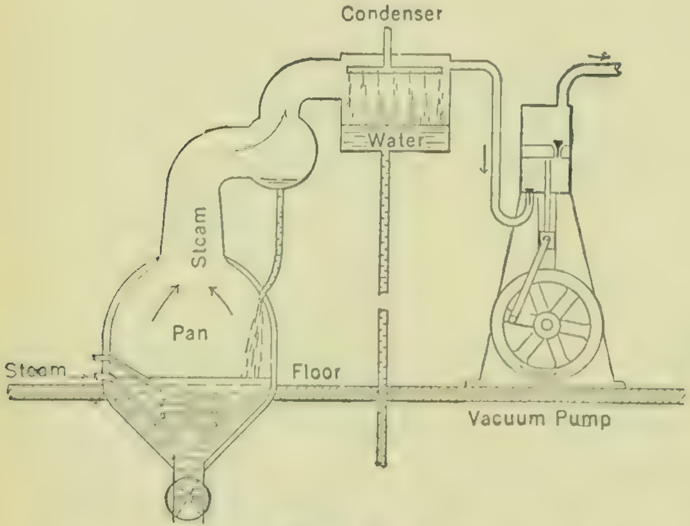


FIG. 65.
In such a vacuum pan water can be distilled from a sugar or salt solution at reduced pressure, and, therefore, at a much lower temperature than 100°C.

We must remember that the temperature at which water boils depends on the **pressure** of the atmosphere at the time. As we ascend a mountain, and leave more and more of the atmosphere below us, water boils at a lower and lower temperature. The steam bubbles need less and less force to push themselves away from the water as the air presses less and less heavily upon them. The boiling point is lowered about 1° C. for every 960 feet we ascend above sea level. Thus water boils at 92.3° C. at Mexico City, 7500 feet above the sea. At Denver, 5500 feet high, it boils at about 95° C. At about what temperature would it boil on Pike's Peak, 14,108 feet high? At the top of Mt. Everest, 29,002 feet above sea level?

In a **closed** vessel we can make the pressure greater or smaller than that of the atmosphere, and therefore can boil water either above, or below, 100° C. To boil water at a **lower** temperature than 100° C. we use a "vacuum" or "reduced pressure" distilling apparatus (Fig. 65). To boil water **above** 100° C. we use a vessel like a **pressure cooker** (Fig. 66). As the water is heated in such a vessel, more and more steam is compressed into the space above the water; under this increased pressure steam finds it harder to push itself away from the liquid water, and the boiling temperature is above 100° C. When the steam has twice the atmospheric pressure, water boils at 121° C. In a locomotive boiler producing steam at 13 "atmospheres" pressure (191 lbs. to the square inch), water boils at 192° C., or 378° F. The force exerted by high-pressure steam when it is allowed to expand is the cause of motion in a steam engine (see § 112).

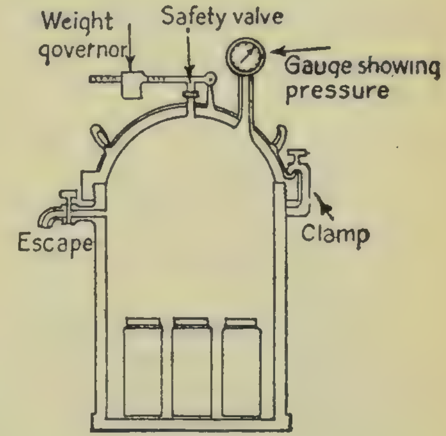


FIG. 66.
The pressure cooker is a boiler in which steam can be confined until it has a desired pressure. Food can thus be cooked at temperatures which are higher than that of ordinary boiling water.

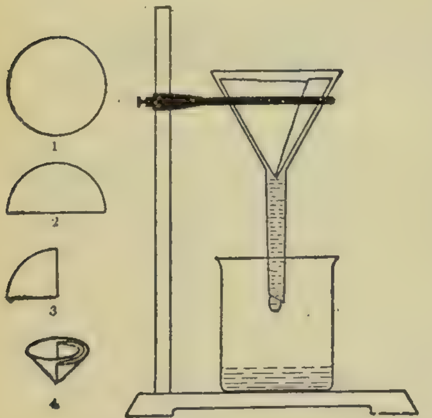


FIG. 67.
Figures 1, 2, 3, and 4, on the left, show the stages in the folding of a circular filter paper. The completed paper (Fig. 4) should fit nicely into the funnel. It should be wet with water before a water solution is poured through it.

90. How Water is Filtered.—

If you look into a chemist's laboratory, you will often see him pour a mixture of a liquid and a solid into a funnel (Fig. 67) holding a folded, porous paper called a **filter**. Only liquids and dissolved substances can pass through the filter paper. There are **household** filters in which charcoal and gravel are the filtering materials. There are also filters of porous stone, which can be attached to faucets. Water filters remove the impurities that are suspended in the water, including the bacteria; but unless the filter is cleaned often it may become so clogged with dirt that it will form a dangerous breeding place for bacteria, instead of removing them. Water filters should be cleaned often and exposed to direct sunlight. Why?

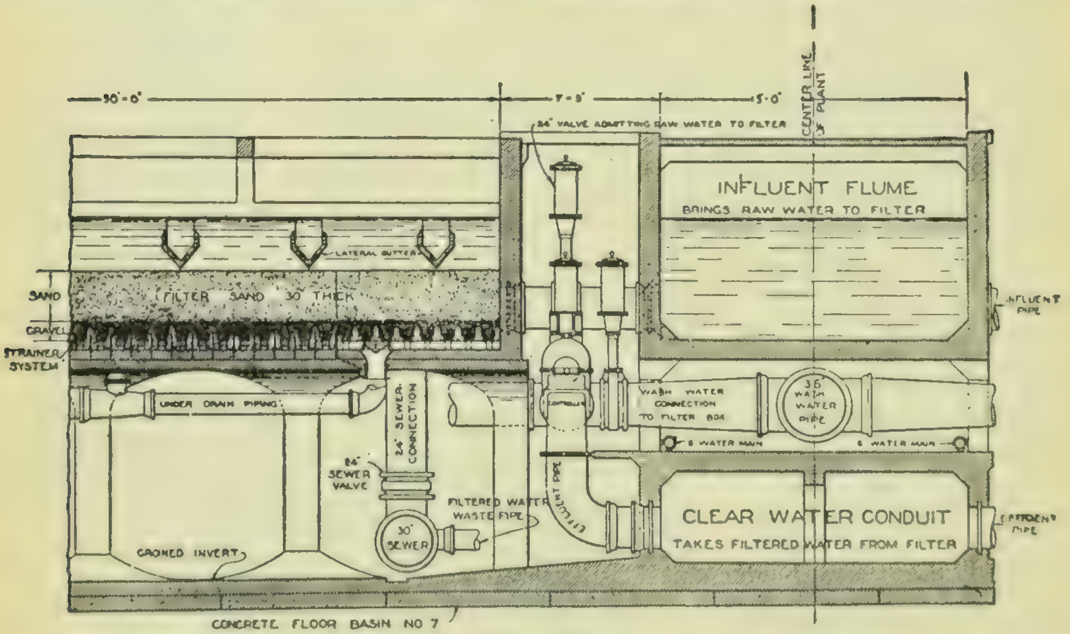


FIG. 68.

The St. Louis Water Purification Plant. Section through the Operating Gallery and Filter Box. The entire supply is taken from the Mississippi River through two Intake Towers located at the Chain of Rocks, about 10 miles north of the Eads Bridge. The water is pumped into seven Settling Basins having a combined capacity of about 200 million gallons.

Filters for City Water.— The best natural filtering material is clean **sand**; sand beds, often acres in extent, are used to filter city water (see Fig. 68). The sand is loose, and contains much air; the oxygen of the air and oxidizing bacteria (see § 30) can thus penetrate far into it and destroy harmful bacteria. After soaking through the sand, the water enters reservoirs, from which it is pumped through the water "mains" to the houses. But the large filters, like the small ones, must be emptied often and allowed to lie idle, so that the sand may be purified by sunlight and air. Coal dust is often mixed with the sand to improve the filter.

91. How Water is Purified by Chemicals.— **Alum** is sometimes added to water before the water enters the sand filter. The alum causes dirt particles, which often settle only very slowly, to flock together (*coagulate*) and come down rapidly, carrying decaying matter and germs with them. Other chemicals are used to destroy the bacteria directly. One of these is **chloride of lime,** or "bleaching powder," a white solid that can be bought in metal cans. A small amount of it added to the city's water supply will make the water safe to drink, but it may give the water a slight taste. A simple method of purifying drinking water for the household is the following:

Rub an even teaspoonful of fresh chloride of lime with a little water until you have a smooth paste. Then mix the paste with 4 cupfuls of water. Pour this mixture into a bottle and let it settle, keeping the bottle tightly stoppered. To purify 2 gallons of water add a teaspoonful of the clear chloride of lime solution, stir up the water, and let it stand for 10 minutes.

92. What is Hard Water?— Chemicals are added to some natural waters not only to make them fit to drink, but also to make them useful for bathing and the washing of clothes. Have you ever noticed that in the "soft" rain water of a cistern, soap forms a **lather,** or suds, quickly and easily, while in the "hard" water of a well or spring the soap lathers with great difficulty? Rain water is always soft; so is distilled water and the water from melting ice. Since well and spring waters were once rain water, they must have become hard in their passage through the ground, by taking up certain substances in solution.

Hard water is objectionable, not only in the household, but also in the factory. The **factory** needs water which can be used in boilers, to produce steam (see § 85). If a boiler is filled repeatedly with hard water, it becomes clogged with a deposit — boiler scale — just as a teakettle does (Fig. 69). Boiler scale is so poor a conductor of heat (see § 42) that a boiler containing much of it must be heated very hot, or the water will not boil. As a result of this over-heating, the scale acts upon the iron, weakening it. Boiler scale has caused serious explosions and loss of life.

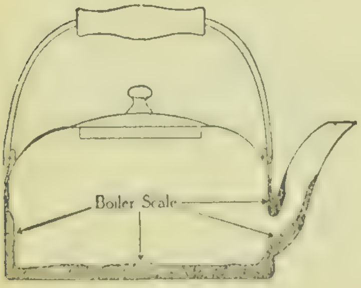
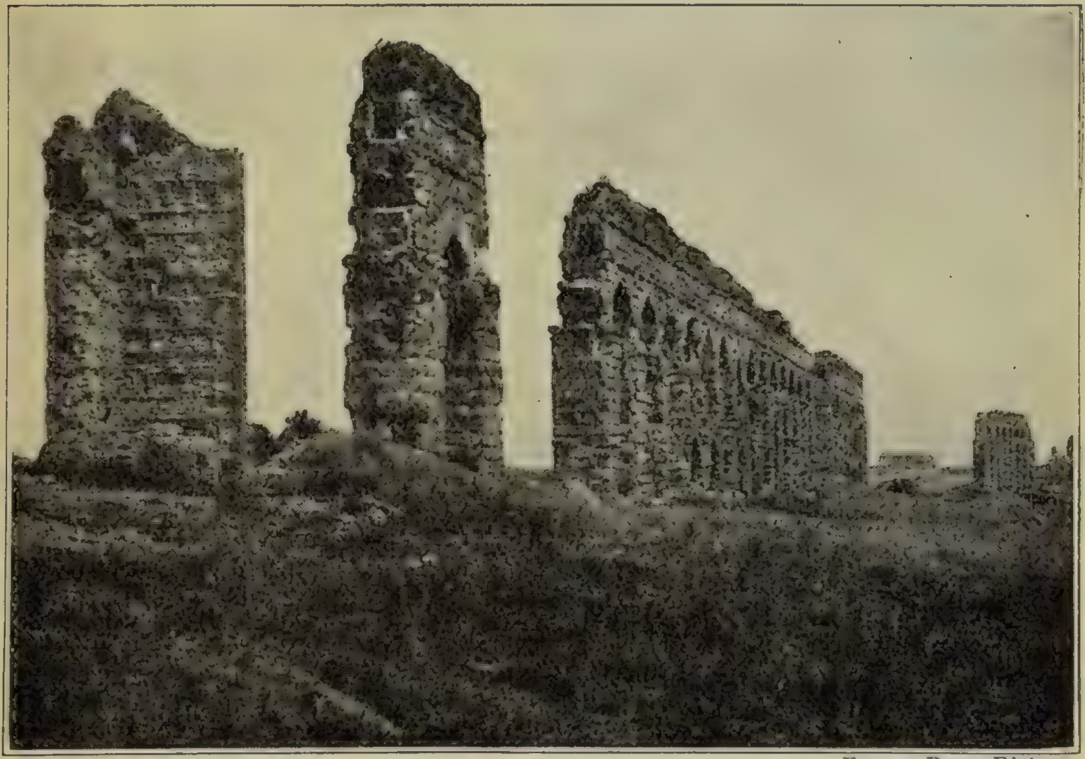


FIG. 69.
The inside of the kettle is lined with a solid crust, or "scale," deposited from hard water when it was boiled.

Hard water is **softened** in many ways. **Soap** does it; in fact, hardness of a water may be defined as its **soap-consuming** power. A permanent lather is not formed in hard water until the materials causing the hardness are removed by the soap. **Soda** will soften water; so will **ammonia** water. Some of the materials causing hardness are made insoluble, and settle out, when the water is boiled; in this case the hardness is said to be **temporary.** Hardness that cannot be removed by boiling is called **permanent** hardness. To remove permanent hardness we need to add some softening material.

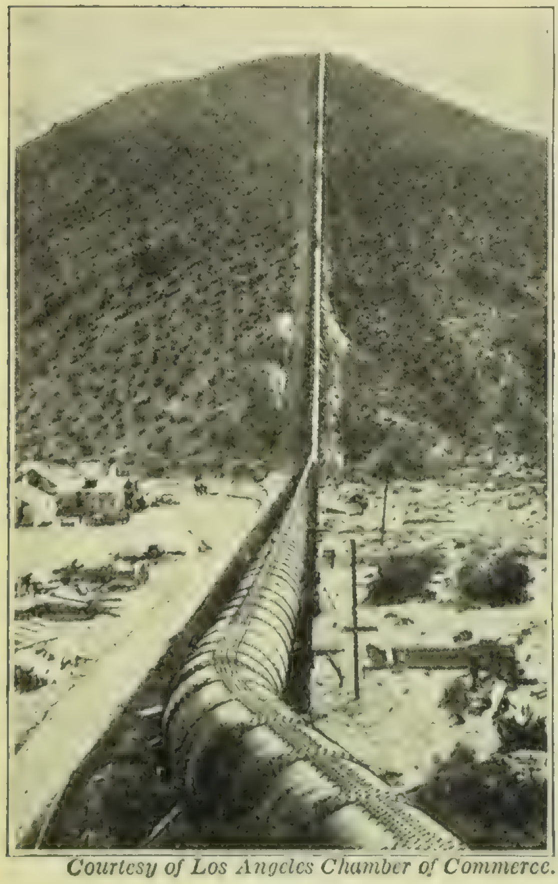
93. Water Supply and Sewerage.— From what source does your community get its water? The Romans built great **aqueducts** (Fig. 70) to bring water from the lakes of the Apennines to Rome. New York City now gets its water, through an aqueduct, from the Catskills, 90 miles away. At one place the water is carried under the Hudson River. Los Angeles gets its water from mountain lakes and rivers 226 miles away (Fig. 71). The cities on the Great Lakes get their water from the lakes. As the sewage from the city may pollute the water, the "intakes" are usually several miles from shore. Even so the sewage sometimes pollutes the water; hence Chicago has built



From a Perry Picture.

FIG. 70.
Aqueduct of Claudian, Rome.

the "Drainage Canal," at great cost, to carry water from Lake Michigan into the Illinois River; thus it sends the city's sewage finally into the Mississippi.



Courtesy of Los Angeles Chamber of Commerce.

FIG. 71.

Los Angeles Aqueduct: Jawbone Siphon, looking south. An automobile, or a wagon team, can be driven through a section of the conduit.

It is necessary that city water shall have some pressure in the pipes, so that it will rise to the top floors of tall buildings, both for ordinary use and in case of fire. Some cities get their water to flow by a "*gravity*" system; because the water level of some stream, or lake, or reservoir, near the city is higher than any of the buildings. The water simply flows downhill to the city and up into its buildings. **Denver** has such a system. When a gravity system is not possible, water is often raised, by means of a strong force pump, into a high tank, reservoir, or "standpipe"; from this it flows as in a gravity system.

We have already studied the working of the common lift pump (see § 14). A fire engine is an example of a **force pump** (Fig. 72). There is no valve in the piston of the force pump. When we raise the piston, the pressure of the atmosphere forces water into the cylinder. When we force the piston down, the water below it closes the cylinder valve. The water cannot go either up or down; so it goes through the discharge valve into a tank containing some air (an air chamber). The air is compressed by the pressure of the water. When we raise the piston once more, the water forced through the discharge valve "backs up," closing this valve. When we force the piston down again, the process is repeated. In a force pump there is a constant stream of water. Between the strokes of the piston, when the piston itself is not forcing the water out, the compressed air in the air chamber is doing so (see § 11). What advantages has a force pump over a lift pump?

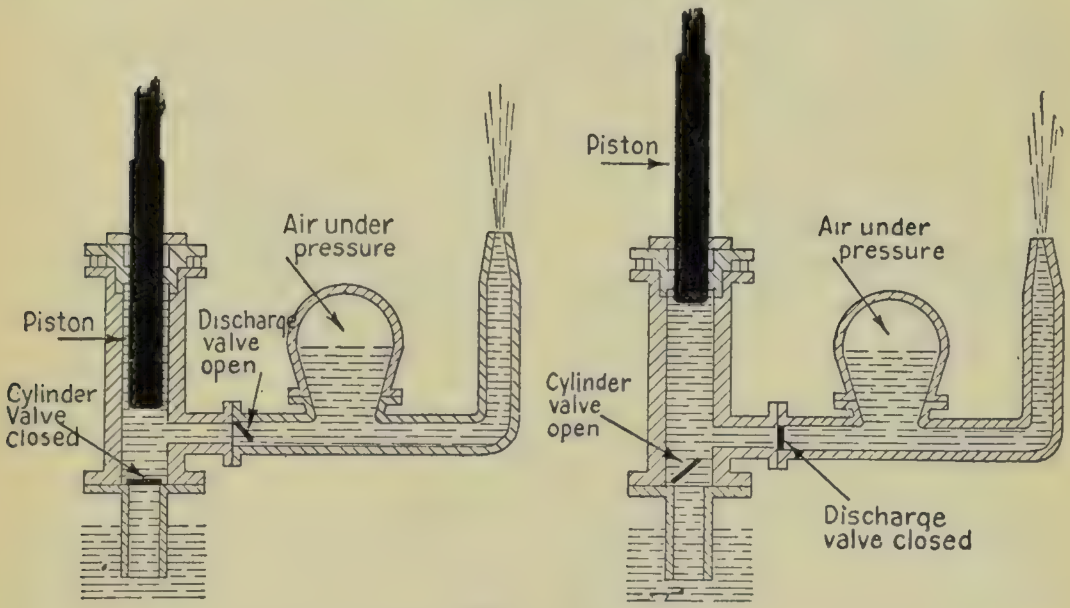


FIG. 72.
A force pump. Two positions of its piston and valves, but a steady stream of water.

94. A Water Supply in the Country.— When we dig a well, do we strike underground streams or "veins" of water? No, we simply make a hole into which the "groundwater" can flow. This is the water which **saturates** the ground everywhere below certain levels (see § 86).

Deep wells are not dug, but **drilled,** or bored, through soil and rock, until a level is reached at which good water in large enough amount enters the well. The deeper a well is, the larger is the extent of ground from which the water will be collected, and the more likely it will be to last in dry weather. **Artesian wells** are deep wells drilled through a layer of rock or clay which holds the groundwater under great pressure. When we pierce the

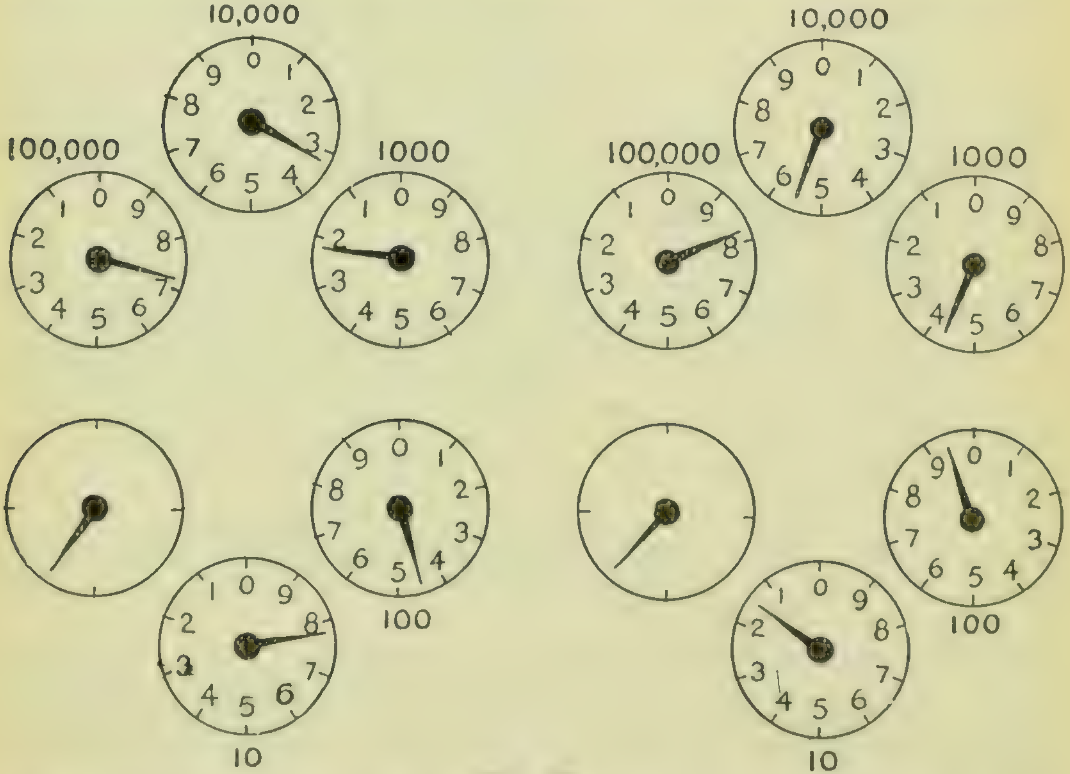
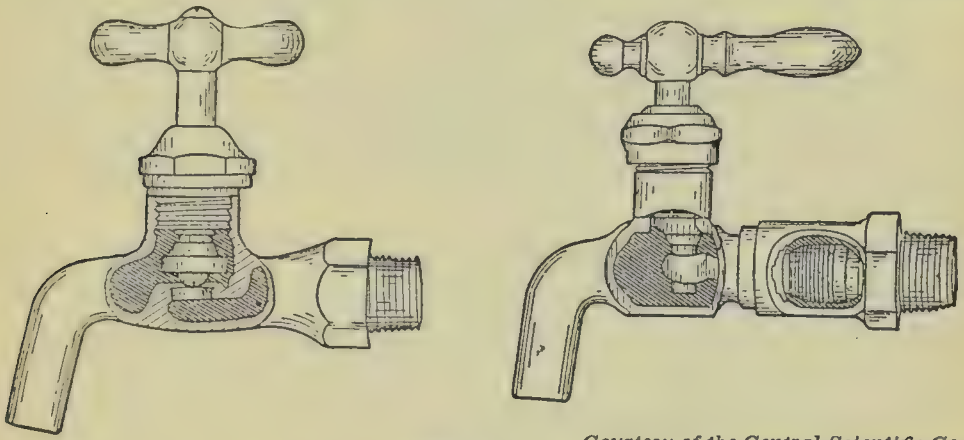


Fig. 73.

Two positions of a water meter. Note that each dial measures up to the number placed near it. Thus, the bottom one measures up to **10** gals., the next one above it, on the right, up to **100** gals., and so on. Note also that some of the dials are to be read in the direction of the hands of a clock, the others in the opposite direction. When the hand on the bottom dial has gone around once, **10** gals. have been used, and the hand on the "100" dial has gone from **0** to **1**. When the "10" dial has gone around 10 times, that on the "100" dial has gone around once, and the hand on the "1000" dial has gone from **0** to **1**. The dial with no readings shows whether, or not, water is flowing through the meter Read the first meter; then the second. What is the difference between them?

covering layer, the pressure upon the water forces it to the surface and sometimes high into the air.

When water soaks into the ground until it reaches a layer of rock or clay that it cannot penetrate readily (Fig. 61, § 86), it collects above this layer. If the ground slopes, so that the rock layer comes near the surface, as on the side of a hill, the water bubbles out as a **spring.**



Courtesy of the Central Scientific Co.

FIG. 74.

The faucet on the left is a compression bibb; its handle must be turned until the rubber tip closes the hole below it. The faucet on the right is of the Fuller type. In the cut the faucet is open; we close it by pulling the handle forward. This pulls the acorn-shaped rubber "gasket" forward, so that it closes the opening through which water enters the faucet. Both faucets are shown with part of the sides removed.

95. Plumbing.— Find out how much water your family uses in a given month or quarter, and what it costs. In some cities water is sold at a "flat rate"; no matter how much you use, you pay a fixed sum. Usually a **meter** is put into the house to measure the amount that flows from the street mains into the house (Fig. 73). "Plumbing" comes from the Latin word for **lead**; why? Plumbing includes the pipes and faucets through which fresh water comes into the house, as well as the pipes and traps through which waste water is carried away.

Iron pipes, as well as lead ones, are used for plumbing; the iron is "galvanized," or covered with **zinc,** to prevent its rusting.

Lead is used because it does not rust easily. Lead pipes may be bent around corners; they may also be cut where necessary, and the pieces joined by soldering. Lead water-pipes have one disadvantage: when they are new, the surface in contact with water may be oxidized to poisonous compounds that dissolve in the water. These compounds may cause serious sickness; hence we should always let water run for a minute from new pipes. After a time most water forms a coating on the inside of the pipe; this protects the lead and the water.

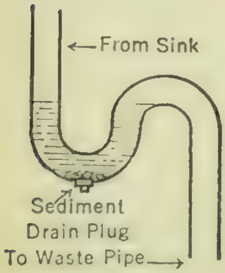


FIG. 75.
A trap or water-seal.

Faucets, also called hydrants, or bibbs, are of several forms (Fig. 74); they are usually made of brass. A **trap** (Fig. 75) is a part of a waste pipe so bent that it remains full of water; it thus forms a "water-seal," and prevents sewer air from entering the house. Water should be run through all traps, including floor drains, every day or two, so that the water-seal may not be broken.

96. Ice Making.— What a blessing it is that we can have ice in summer to cool our drinking water and to keep our food from spoiling! The supply of natural ice is so uncertain, especially in warm climates, that men have been obliged to make ice by **artificial** freezing.

The **principle** upon which artificial freezing is based is that the rapid *evaporation* of a liquid *requires heat.* The heat comes from whatever is in contact with the evaporating liquid. We have already learned that this is true in the evaporation of the perspiration (see § 54).

The **apparatus** for preparing artificial ice is partly explained by Fig. 76. The liquid which is evaporated is

liquid ammonia. This is not ammonia water, but the gas, *ammonia*, which has been changed into a liquid by *compressing* it. When the gas is compressed into the liquid form, it becomes **hot**; hence it must first of all be cooled to the ordinary temperature. The cooling is done by sprays of water. By this combination of compression and cooling liquid ammonia is formed.

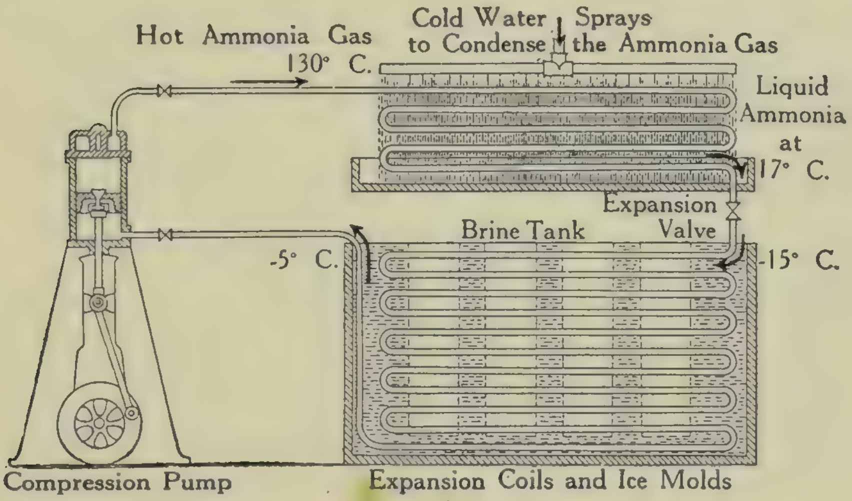


FIG. 76.

Liquid ammonia (produced by the compression of gaseous ammonia) is allowed to boil rapidly. In so doing it takes up heat from the salt brine and cools it below the freezing point of water.

When the pressure upon the liquid ammonia is removed, the liquid **boils** vigorously at the ordinary temperature. Review § 87 for the effect of pressure upon the boiling point of water. When the ammonia boils, it **takes up** a great deal of **heat**: just as much as was given off when the ammonia gas was turned into a liquid. So the pipes in which the ammonia is boiling become very cold, and the salt brine through which they run becomes very cold, too: perhaps −15° C. This cold salt brine is used for cooling purposes, just as hot water is used for heating. If tanks, or molds, of water are put into the brine, heat is taken from the water until it is frozen. Cold brine is also piped through cold-storage warehouses and refrigerator cars. In this way butter, eggs, meat, and fruits are kept cold to prevent their spoiling. **Iceless refrigerators** are now made which are cooled by small machines that compress ammonia and then cause it to evaporate rapidly (see § 54).

How Ice Cream is Frozen.— As all of us know, we freeze ice cream by placing it in a pail surrounded by salt and crushed ice. As the handle of the freezer is turned, heat is taken from the pail and cream until the cream is frozen. But why does a mixture of salt and ice give a lower temperature than ice alone?

When we put ice into water having the room temperature, the ice melts. What is the source of the heat needed to melt the ice? It comes from the water. If there is enough ice, the water is cooled to 0° C., the temperature of melting ice and freezing water (see § 52). When we put salt upon ice, the ice begins to melt, forming water, and the salt dissolves in the water, forming brine. The ice is really melting in salt brine, and the heat needed for the melting comes from the brine. But salt brine does not freeze until it reaches a temperature of about −20° C.; hence the melting of the ice will continue until this temperature is reached. When cream or "ices" are placed in the brine, heat is taken from them until they are frozen.

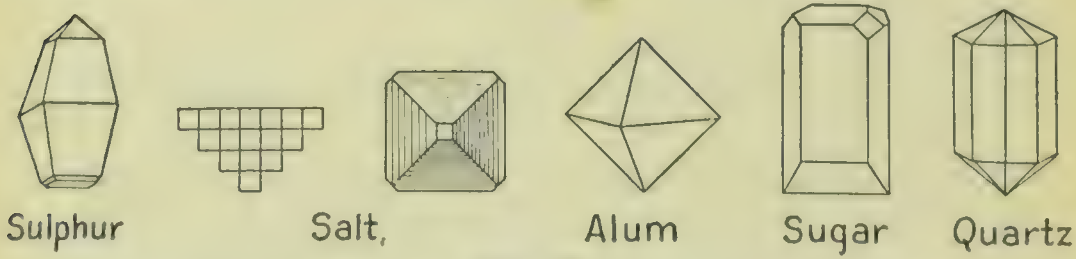
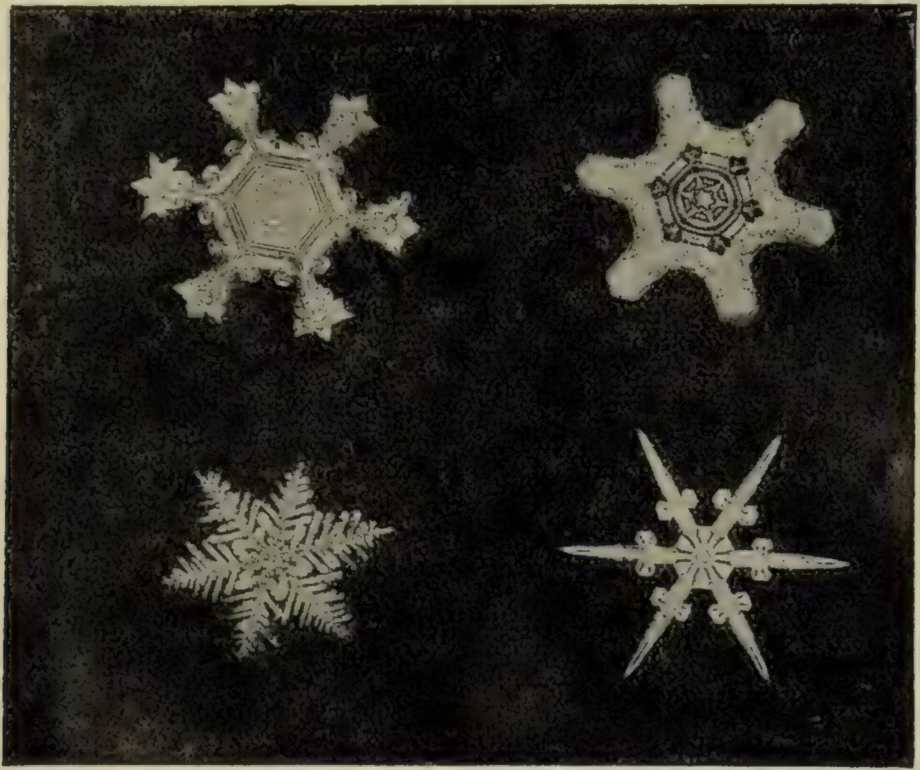


Fig. 77.
Crystalline forms in which matter arranges itself.

97. How Crystals are Formed.— Have you ever noticed the form of the grains of salt after the water of salt brine has evaporated? They consist of small *cubes*, often arranged in the form of a "hopper" (Fig. 77). We call the cubes **crystals** of salt. Many other substances can be obtained as crystals. If we add to a small amount of hot water, say at 70° C., as much powdered **alum** as the water will dissolve, and then let the solution cool slowly and undisturbed, alum crystals will be formed. Crystals of **blue vitriol** may be formed in a similar way. All crystals have flat faces and straight edges arranged in a definite way.



Photograph by McIntosh Stereopticon Co.

FIG. 78.
Exquisite designs of snowflakes.

Each substance has its own crystalline form, but the crystals will not be perfect unless they are kept away from the sides and bottom of the vessel. The more slowly crystals separate from solution, the larger they will be. **Sugar** may be crystallized upon a stick or string suspended in a sugar solution; it is then called **rock candy.**

Alum may be crystallized in the same way. **Sulphur** dissolves in a liquid called carbon disulphide and crystallizes when the liquid is evaporated.

Crystals are formed not only when solids separate from a solution, but when liquids freeze to form solids. The crystals we know best are those of water in its solid forms: ice, frost, and snow. In ice the crystals are packed closely together. In snow flakes and frost they are separate. Snowflakes are found in many forms (Fig. 78), but all are six-sided or six-pointed.

Some substances, such as glass and many gums, do not crystallize; they are said to be **amorphous**, or without form.

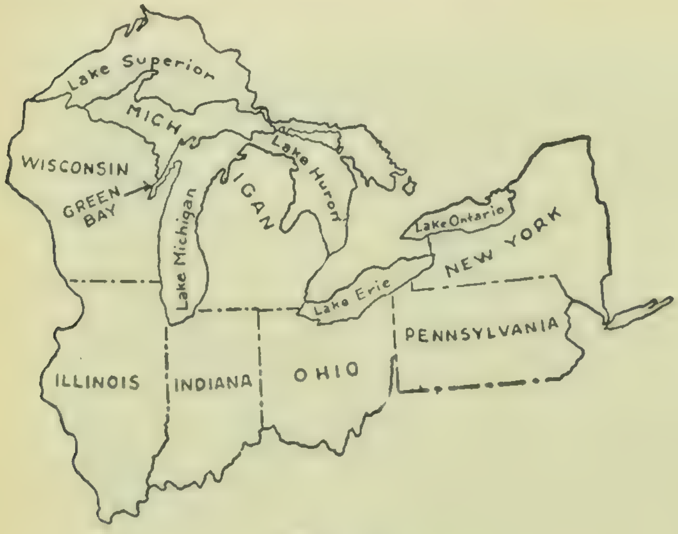


FIG. 79.
The Great Lakes affect the climate of the country near them. Locate upon the map the fruit-raising and summer-resort areas of the Great Lakes Region.

98. How Bodies of Water Affect Climate.— Do you know why peaches can be raised so successfully on the eastern shore of Lake Michigan, grapes on the eastern and southeastern shores of Lake Erie, and cherries on the peninsula between Green Bay and Lake Michigan, in Door County, Wisconsin? (See Fig. 79). The reason is found partly, of course, in the nature of the soil; but chiefly in the climate. The climate, in its turn, is greatly affected by the presence of these large bodies of water.

Water has many peculiar properties. One of them is that so much heat can be stored up in it. If you heat a pound of water, a pound of iron, and a pound of mercury over three burners that give exactly the same quantity of heat, the mercury and the iron reach 100° C. long before the water does. Then, when you stop heating them, the mercury and the iron cool much more rapidly than the water. If you have a pound each of mercury, iron, and water, all three at 100° C., and put each separately into a pan of ice, the hot water will melt about 9 times as much ice as the iron will, and about 33 times as much ice as the mercury will. We say that the water has a greater **heat capacity,** or specific heat, than the mercury and the iron (see Table VII, Appendix). Now the land, like iron and mercury, has a small heat capacity: only about $\frac{1}{4}$ that of water. As a result it is heated up more rapidly by the sun than water is, but it also cools more rapidly. So places inland have great extremes of heat and cold, while a place near a large body of water is kept warmer in winter and cooler in summer because of the presence of the water.

The main reason, then, for the success of fruit culture on the eastern shores of the Great Lakes is that while the prevailing cold winds of winter in this region are from the northwest, the winds are warmed as they blow over these bodies of water. Why is the eastern shore of Lake Michigan so popular as a summer resort? Why do people go to the seashore in hot weather? So great is the effect of water upon climate that there are islands in the Pacific in which the temperature does not change more than 5° or 6° C. in the entire year. The effect of water upon the temperature of the land is much greater if currents of warm or cold water flow along the shore. Thus the shores of Alaska and the Pacific Northwest have a mild winter climate, owing to the Japan Current, and the Gulf Stream carries warm water from the tropics to the western coast of Europe and gives open water to the ports of northern Norway. Partly because it is surrounded by water and partly because of the Gulf Stream, Iceland has a mean January temperature of 30° F., while in Siberia, in the same latitude, the temperature for January is −10° to −40° F.

99. Of What is Water Composed?— When carbon is burned in oxygen or air, it unites with the oxygen, forming carbon dioxide (see §§ 28 and 60). We say that carbon dioxide is **composed of**, or is a **compound** of, carbon and oxygen. Is water a compound, too, made up of two or more substances, or is it a **simple** substance? One way in which this question has been answered has been to pass an electric current through some water. The operation is called the **electrolysis** (ē-lĕk-trŏl′ĭ-sĭs) of water. Electrolysis means "loosing, or breaking apart, by electricity." The experiment may be carried out as follows (Fig. 80):

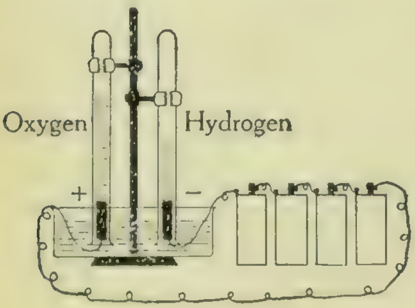


FIG. 80.
A direct electric current of sufficient pressure breaks up water (it is really very dilute sulphuric acid) into hydrogen and oxygen.

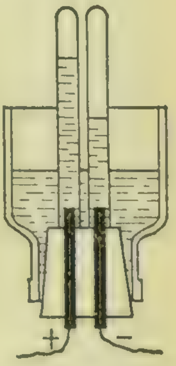
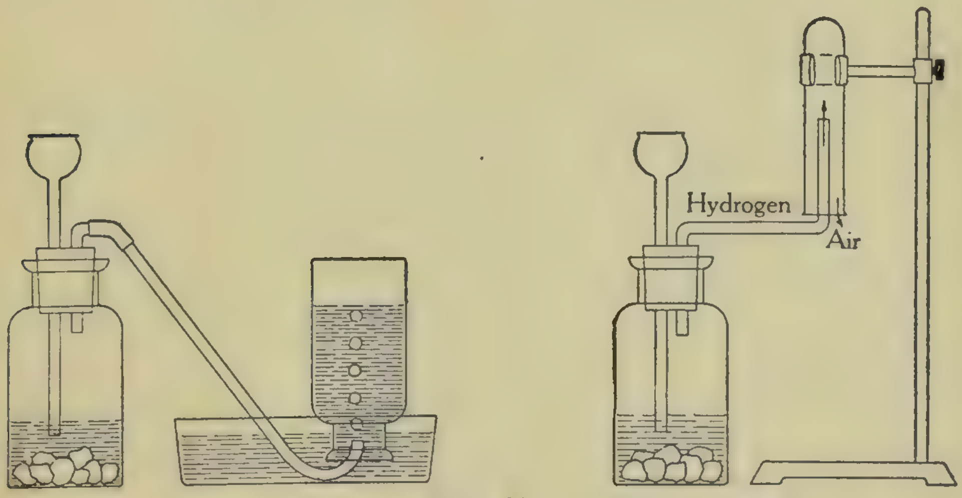


FIG. 81.
Another form of electrolysis apparatus. The top of a bottle is cut off and fitted with a two-hole stopper containing two sticks of gas carbon (discarded electric - arc pencils). In place of the stopper paraffin may be used to support the electrodes. It may be poured, in the melted condition, into the neck of the bottle.

Let two wires from a battery of several cells, or from a storage battery or other source of the **direct** current, pass into a vessel containing water and a small amount of sulphuric acid. The wires inside the vessel are of platinum (see, however, Fig. 81 for a substitute), and they have tips of platinum foil so as to make their surface larger. We call the ends of the wires the **poles** of the battery. If we were to put the poles together, the current would have a complete path, or

circuit, without going through the dilute acid. But if we keep the poles apart, the current must pass through the dilute acid. As an electrician would say: The dilute acid **closes,** or **makes,** the circuit.

While the current is passing, **bubbles of gas** arise from each pole. If we put over each pole a test tube filled with the dilute acid, we can collect the gas bubbles. The gas collects in one tube about twice as rapidly as in the other. If we put a burning splinter into the gas that is collected the more slowly, the splinter burns more brightly than in air. If the splinter is only glowing, it will burst into flame. The gas in this tube is **oxygen.** Is it possible that water, like carbon dioxide, is an **oxide?** See § 29. If we bring a flame near the mouth of the other test tube, the gas takes fire with a slight explosion, or "pop," and burns with a blue flame that is almost invisible. This gas is called **hydrogen,** meaning "water-former." The Greek word for water: *hydor,* is a part of many other English words. One of them is *hydrant*; consult a dictionary for others.



a. FIG. 82. *b.*

a and *b.* Apparatus in which hydrogen is being prepared from zinc (or iron) and a dilute acid. It may be collected "over water" or "over air." Compare the method with that for carbon dioxide (§61).

100. How to Prepare Hydrogen in Quantity.— As we have just learned, we can break up water by means of the electric current, and so prepare a quantity of hydrogen for study. It is easier, however, to prepare it from an **acid** and a **metal.** Marble and hydrochloric acid **effervesce,** or foam, vigorously when brought together (see § 61), the gas given off being carbon dioxide. When dilute hydrochloric acid is put upon **zinc** or iron, there is also a foaming; but in this case the gas is hydrogen. The hydrogen is present in the acid; the action of the metal sets the hydrogen free.

The **apparatus** needed to prepare and collect hydrogen (Fig. 82, *a*) is a bottle provided with a stopper having two holes, a "thistle" or funnel tube, and a delivery tube reaching to a water pan. The thistle tube allows us to add fresh supplies of the acid; it also lets the hydrogen escape if the delivery tube becomes stopped up. Hydrogen may be collected over water, as oxygen and carbon dioxide are. Do you think it is very soluble in water?

We can also collect hydrogen "over air," as shown in Fig. 82, *b*. Does this indicate that it is heavier, or lighter, than air?

Hydrogen is colorless, like oxygen, air, and carbon dioxide. As we prepare it, it has a slight odor, but the pure gas is odorless. It is the lightest substance known: air is 14.4 times as heavy as hydrogen; oxygen is 16 times, and carbon dioxide is 22 times as heavy. It takes about 15 gallons of hydrogen to weigh as much as a nickel five-cent piece.

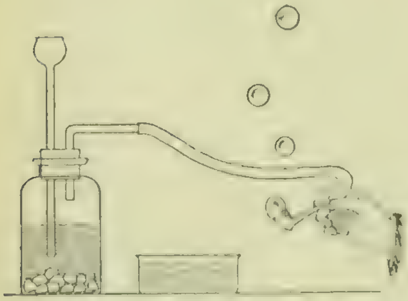


FIG. 83.
Soap-bubble balloons filled with hydrogen rise in the air.

We can take advantage of the lightness of hydrogen to prepare soap-bubble balloons (Fig. 83). For this purpose attach a clay pipe or a thistle tube to the delivery tube. Is hydrogen used to fill airships? See § 152.

101. What is Formed When Hydrogen Burns?— First review § 25. When a substance burns in air, with what does it unite? What materials are formed when the electric current is passed through water? What substance, then, might we expect to be formed when hydrogen burns in air?

How to Light Hydrogen Safely.— Hydrogen may be burned in the apparatus shown in Fig. 84. Care must be taken that **no air** is mixed with the hydrogen; otherwise there may be a **serious explosion.** When we begin the preparation of hydrogen, the bottle is full of **air** (see § 8); hence the first portions of gas that come off are a mixture of hydrogen and air. The following is the **safety test;** it should always be made.

First be sure that the gas is coming off rapidly. If the action between the acid and metal is slow, add a few drops of a solution of copper sulphate (blue vitriol) to the materials in the bottle. Put a test tube down over the outlet tube for a **full** minute; then carry the test tube, mouth downward, to a flame at least 3 feet away. The gas in the test tube "pops" loudly, if it still contains air; but if it is fairly free from air, it burns quietly. Carry the test tube of burning hydrogen back to the jet of hydrogen, repeating the operation, if necessary, until the jet of hydrogen is set on fire.

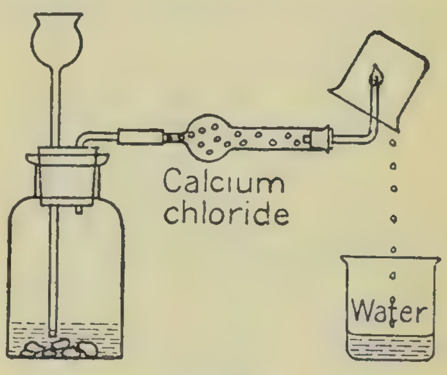


FIG. 84.
Hydrogen burning. Be sure to make the **safety test** before lighting the gas. The calcium chloride removes all water vapor from the hydrogen before it burns; hence the water must be formed by the burning. With what element does the hydrogen unite?

The hydrogen flame is nearly **colorless,** but very **hot.** If we put a vessel over the burning jet, mist will soon collect inside; then drops of **water** appear. Water is formed when hydrogen burns in air.

When a vessel of cold water is put over a gas flame, water drops are deposited on the bottom of the vessel; what is the source of this water? It is formed by the **burning** of the hydrogen and hydrogen compounds in the gas. Would you expect water drops to be deposited when the vessel becomes hot? If a fuel contains carbon and hydrogen, what products are formed when it burns?

102. Elements and Compounds.— The electrolysis of water was a great triumph for science. Has the question come to you: "Can hydrogen and oxygen, in their turn, be broken up into other substances, as water is?" The answer is that they never have been divided by any method used. A substance like water, which is not mixed with anything else, and which has at least two kinds of matter combined in itself, is called a **compound.** A kind of matter like hydrogen or oxygen, which we cannot by ordinary means break up, is called a **simple substance,** or **element.** Carbon, nitrogen, iron, tin, mercury, and phosphorus are elements, too. In all there are probably only about 90 elements, but several hundred thousand compounds. Most compounds are made up of only 2, 3, or 4 elements. Thus we make up all our words out of 26 letters.

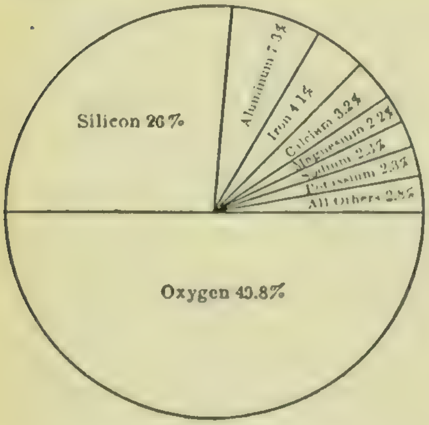


Fig. 85.
Per cent of the earth's crust made up of the different elements.

If we pass the electric current through concentrated **hydrochloric acid** (see § 99), we can collect **hydrogen** at one pole and a green, suffocating gas called **chlorine** at the other; hence we conclude that hydrochloric acid is a **compound** of hydrogen and chlorine, just as water is a compound of hydrogen and oxygen. Do you think **common salt** is an element or a compound? When it is melted (this requires a temperature of 820° C.), and a current of sufficient strength is passed through it, the green gas: **chlorine,** collects at one pole and a silvery, soft solid at the other. The solid is **sodium.** If sodium is put into chlorine gas, it unites with the chlorine, forming **salt** once more; so we conclude that salt is a **compound.** The chemist calls it **sodium chloride** (see § 29), to show us of what elements it is made up.

Mixtures are very different from compounds. When powdered iron and powdered sulphur are rubbed together, we get a **mixture** of two simple substances. If sugar and sulphur are rubbed together, we get a mixture of a compound and a simple substance; sugar and salt form a mixture of two compounds. **Soil** is a mixture of many substances. **Natural water** is a mixture too (see § 86). **Air** is a mixture of **gases**: nitrogen, oxygen, water vapor, carbon dioxide, and small amounts of other gases (see §§ 24, 64, and 78).

103. Physical and Chemical Changes.— We have learned that there are several hundred thousand compounds, besides the 90 or so elements; how can all these substances be distinguished from one another? No two are exactly alike, but each one has a set of *qualities*, or **properties,** of its own. If there is a change in properties, we know there has been a change in the substance. Thus liquid water becomes a gas (water vapor) or a solid (ice); a "tin" can rusts away; milk sours; fruit decays; a rocky cliff gradually becomes changed into chips and dust.

If we heat a poker in a fire, it becomes red hot and gives off heat and light. But if we remove it from the fire, it becomes cold again and has about the same properties as before heating. Coal may be broken into pieces, and the pieces sorted according to their size, but the coal is not really altered. The water in a teakettle may be changed to vapor (steam), then carried away by air currents, and finally appear again as dew or frost on the window pane. Such changes, which do not really alter the nature of a substance, are called *physical* changes.

If we leave the iron poker in a damp cellar, it *rusts*. If we burn the coal, its carbon disappears, and carbon dioxide is formed. If we electrolyze water, it too disappears, and we get hydrogen and oxygen in its place. Such changes *do* alter the nature of the substance. They are called **chemical** changes. Chemical changes are also called **reactions.**

The smallest particles of water are **molecules** (see § 49), but scientists believe that each molecule of steam (water in gaseous form) contains two **atoms** of hydrogen combined with one **atom** of oxygen. The molecule of steam is therefore represented by the letters HOH, or H_2O. The molecule of salt is represented by $NaCl$, and that of carbon dioxide by CO_2.

104. Summary.— We need an **abundance** of water for our houses, our industries, and our community life.

Water exists as **solid, liquid,** and **vapor**; but natural water is rarely pure. Water is the best of **solvents.**

Water **boils** at 100° C. under standard pressure. It **freezes** at 0° C.; but is most **dense** at 4° C. **Ice** is 0.92 as heavy as water.

Mineral waters contain much solid material in solution. The water of the sea is 2.7% common salt.

Drinking water is pure if it does not contain too much mineral matter, and if free from injurious living forms, or "germs."

We **purify** natural water by distillation, boiling, filtration, and addition of chemicals.

Distillation is changing a liquid to its vapor, so as to leave impurities behind, and then condensing the vapor to liquid.

Filters remove the impurities suspended in water, and give a large surface upon which oxidizing bacteria can act.

Soft water is water that readily forms a lather with soap.

Great cities go to enormous expense for the sake of good water.

A **force pump** gives a constant stream of water.

Wells go below levels at which the ground is saturated with water.

Plumbing is the system of pipes and tanks which brings water into the house and carries away water and waste from it.

Traps, or water-seals, keep sewer air out of the house.

Artificial cooling is based on the principle that evaporation requires heat. The liquid evaporated in ice making is liquid ammonia.

In a **freezing mixture** of salt and ice the ice melts in salt brine. The heat required to melt the ice comes from the material cooled.

Crystals are the regular forms taken by most solids when they separate from the liquid condition or from solution.

Water has a great **capacity for heat;** hence seas and lakes heat up more slowly than the land. They also give up heat more slowly. Therefore places near the water have a more uniform climate than places inland.

Water is a **compound** of hydrogen and oxygen.

Hydrogen may be prepared from certain acids by the action of certain metals; also by the **electrolysis** of water.

Hydrogen **burns** in air or oxygen to form **water.**

A **compound substance** contains two or more kinds of matter combined; a **simple substance** is made up of only one kind of matter. **Mixtures** contain two or more kinds of matter, but **not combined.**

The **properties** of a substance are the qualities by which we tell one substance from another.

Chemical changes alter the nature of substances; **physical changes** do not.

105. Exercises.— 1. What advantage has water over carbon dioxide as a fire extinguisher? What disadvantage?

2. Why does a potato lose weight when baked?

3. Why are crackers less crisp in the open than in a tight box?

4. Why does an apple in a cooky jar make the cookies mellow?

5. Why does candy become sticky in damp weather? Why does salt "cake"?

6. How is fresh water prepared from salt water on a ship at sea? How is it done in Nature?

7. Do lakes and ponds generally freeze to the bottom? Would they be more, or less, likely to, if ice were heavier than water?

8. The Jordan River drains Lake Utah, and flows into Great Salt Lake. Ought Lake Utah to have fresh water, or salty? Why?

9. Why should dirty water never be thrown near a well?

10. What causes the bursting of water pipes in winter? Why is it harder for running water to freeze than still water?

11. How does the freezing of the ground help to break it up for the next year's crops?

12. What are the dangers in drinking surface water?

13. Name the ways for purifying water. Which is most used in large cities?

14. What is the value of a trap in the drain pipe of a sink?

15. Why should bottles of ammonia, gasoline, and turpentine be kept closed?

16. If sugar is dissolved in tea, is the tea cooled? Why?

17. Which should be kept colder in a storage warehouse, eggs or meat?

18. At Quito, Ecuador, water boils at 90° C. Why? This temperature is too low for the cooking of potatoes. How could water be made to boil at 100° C. in Quito?

19. Give the three chief ways in which water that falls as rain is removed.

106. Projects.— 1. Find out what ponds and streams there are in your neighborhood, and if they freeze to the bottom; also what plants and animals live in them through the winter.

2. Determine if water is deposited on cold vessels set over gas flames.

3. Find the weight of 100 cu. cm. of water at about 4° C.

4. Find the weight of a pint of water, and from the result calculate the weight of a cubic foot, in pounds. See Appendix II.

5. Find the weight of a cubic centimeter of ice, and compare it with that of the same volume of water. SUGGESTION: Out of doors, on a cold day, saw out a block of ice of convenient size, measure its dimensions, and calculate its volume. Then (inside the room) weigh the ice in a dish previously weighed. Does it matter if the ice melts while you are weighing it?

6. Show that water expands on freezing. SUGGESTION: Completely fill a small baking-powder can with water, tie on the cover, and set the can outdoors on a cold night.

7. Devise an apparatus for distilling water, and carry out the process.

8. Prepare a freezing mixture, get its temperature, and freeze milk in it.

9. Freeze water by the rapid evaporation of ether. SUGGESTION: Put a drop of water on the bottom of a test tube (outside), put a teaspoonful of ether into the tube, and force bubbles of air (a bicycle pump will give them) through the ether. CAUTION: Ether is very *inflammable;* remain away from all flames while working with it.

10. Prepare crystals of rock candy from an almost saturated sugar solution.

11. Prepare crystals of alum from powdered alum. SUGGESTION: Dissolve alum in very hot water in the proportion of 10 grams of alum to 20 cu. cm. of water, and let the solution cool slowly.

12. Determine if the temperature of water is affected by dissolving a crystalline solid in it. SUGGESTION: Use 8 grams of sodium nitrate to 10 cu. cm. water, and note the temperature that results.

13. Get the density of a saturated salt solution by means of a hydrometer. Can you use a battery "tester"?

14. Make a hydrometer out of a slender stick of some very light wood, by attaching a sufficiently large piece of sheet lead to make the stick float upright in water. Mark the depth to which your

hydrometer sinks into kerosene, water, and saturated salt solution. It is best to paint or shellac the stick before using it, so that it will not become soaked with the liquids used.

15. Examine the inside of an old teakettle, take out some of the deposit, and add some acid to it. Report how you would prove that any gas given off is carbon dioxide.

16. Put some clean pebbles into a teakettle that is in daily use. Leave them for several weeks; then remove them and report the result to the class.

17. Test several samples of water, such as rain water, distilled water, city water, well water, and mineral water, for hardness, as in § 92. Make a soap solution from a teaspoonful of soap shavings or flakes and 3 tablespoons of hot, distilled or rain water. Cool the solution. Half fill a clean small-mouth bottle with the water to be tested, add a drop of the soap solution, close the mouth of the bottle, and shake the bottle vigorously. Find how many drops of soap solution are required in each case to produce a good lather, and from this decide which is the harder water. Write a report of your results.

18. Write a paper upon household filters, and report it to the class.

19. Prepare a report upon the water supply of your city or community.

20. Read the water meter in your house once a week for a month. Look up the water bills of your family for the past year, and determine when you used the most water, and how much it cost. Report your results.

21. From a plumber get samples of the different kinds of faucets (bibbs) and traps, and explain their working to the class.

107. References.— ALLEN: *Mechanical Devices for the Home.* HAZEN: *Clean Water and How to Get It.* HESSLER AND SMITH: *Essentials of Chemistry.* HOPKINS: *Elements of Physical Geography.* RITCHIE: *Primer of Sanitation.*

CHAPTER VIII

FORCE AND ENERGY

108. What is Gravity?— Have you ever given thought to so common a phenomenon as the falling of an apple to the ground, and wondered why the apple falls? Why is it that any body which is not supported, or held up, falls? Why is it that a rifle bullet which is shot upward does not continue its flight off into space, but always returns to the earth? **Sir Isaac Newton** gave the reason when he said that the earth **pulls** objects to itself, or *attracts* other objects. Do you suppose an apple hanging upon a tree attracts the earth? Why not? In proportion to its weight it pulls the earth as much as the earth pulls it. It is also just as reasonable to suppose that the earth falls toward the apple as that the apple falls toward the earth. But the distance that the earth **moves** before they meet must, of course, be very small, because of the much greater size of the earth. This **earth-pull** we call **gravity.**

We do not find it easy to picture to ourselves just how the earth's pull is applied. A horse pulling a wagon is *attached* to the wagon, and the strength of its muscles overcomes the tendency of the wagon to remain at rest. But the earth's attraction **acts through space,** without visible or invisible attachment. Can you understand attraction without attachment by the case of a magnet and an iron nail?

Is it possible that there is attraction between any two objects, such as two croquet balls or oranges, lying beside each other? It is not easy to show this, because the earth pulls both objects so strongly toward itself; but by means of a carefully planned experiment it was shown clearly that one body attracts another near it. Two metal balls, one much larger than the other, were hung side by side (Fig. 86), and it was possible for the experimenter to see clearly that the balls moved nearer together. Which do you think would move the farther? So we conclude that this pull, which the earth has for bodies near it, is also present between any two or more bodies. Scientists believe that the same attraction exists between the heavenly bodies, such as the sun, moon, and our earth; in this case it is called **gravitation.**

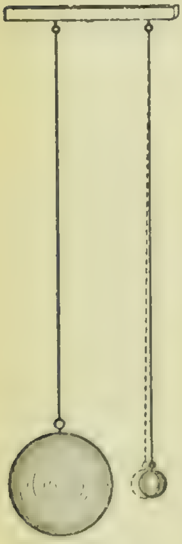


FIG. 86. An attraction, or pull, exists between any two bodies.

109. Why Does a Body Have Weight?—How do we weigh an object, such as a stone? We might use our "sense of weight." In fact, the experienced cashier and baggageman often develop this sense to a remarkable degree, owing to years of experience in the handling of coins and trunks, respectively. But for accurate work we use *balances* and *scales* (Figs. 5 and 6, § 9).

If a balance has two arms of equal length, as in the chemical balance and "trip" scale of the laboratory, the body weighed must be exactly as heavy as the weights used to **counterpoise** it. The object to be weighed on such balances is placed in the left-hand pan, and the weights in the right.

In making a **spring balance** (Fig. 87) the manufacturer stretches the spring by means of weights placed on the hook, and then marks the successive positions of the pointer on the graduated scale. A body which stretches the spring to the same extent as a 3-pound weight must weigh 3 pounds. Scales for weighing heavy objects, such as cars, or loads of hay or coal, are made out of a system of **levers,** so that the whole apparatus can be kept in a small space under the weighing platform.

Why does the weight or object stretch the spring at all? The answer is that the earth *pulls* the matter of the object toward itself, or, rather, that the object weighed and the earth attract one another. We say that **gravity,** or the earth-pull, causes a body to have weight.

We need to distinguish between the **mass** of a body and the **weight** of a body. Newton (§108) saw that the earth's attraction for a body depends upon the **quantity** of matter in the body, and not upon its **kind**. A pound of feathers is attracted with the same force as a pound of lead. The quantity of matter in a body is its **mass**. The **weight** of a body is the result of the earth's attraction, or pull, upon the mass of the body.

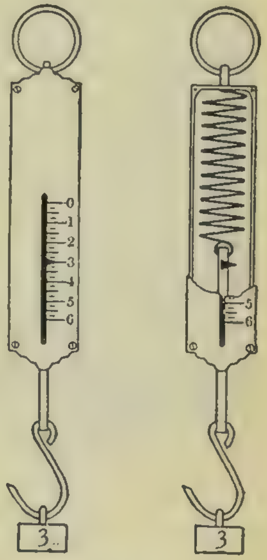


FIG. 87.
The earth pulls the object weighed, and this in turn stretches the spring.

If we remove a body farther from the earth's center, as by taking it "up in the air," or on a mountain top, it will **lose** in weight. It will also lose in weight if we carry it from the North or South Pole to the equator, because at the equator it will be about 13 miles farther from the earth's center (see § 147). For this reason a body weighing 590 lbs. at the poles weighs 1 lb. less at the equator. The **mass** is the same at one place as at the other.

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FIG. 90.
The Leaning Tower of Pisa.

110. In What Direction Does the Earth Pull?

— If you drop a stone, it falls "straight down," or **vertically.** Bricklayers use a string with a weight attached — a **plumbline** — to be sure they are making a wall or chimney vertical. The path of the falling stone, and the position which the plumbline takes, both show that gravity acts vertically.

But objects that are very light, such as feathers and paper, **seem** to fall more slowly than heavy objects. **Galileo** (§114) dropped balls made of different materials from the leaning tower of Pisa (Fig. 90), and as a result insisted that all objects, heavy and light, would fall a given distance in the same time, if it were not for the air, which resists being pushed out of the way. When air pumps were made (see § 11), so that a long tube (Fig. 91) could be freed from air, it was found that a feather falls just as rapidly as a coin or a bullet or any similar object.

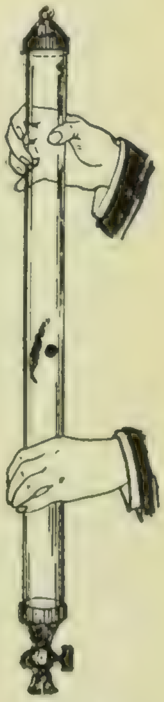


FIG. 91.
In a vacuum light bodies and heavy bodies fall at the same rate.

On a very windy day even a heavy body may not fall vertically. An apple blown off by a gust of wind will go in the direction of the wind (horizontally) as well as downward. It cannot go in either of these directions alone, hence its path is a **curved** one. But it will reach the ground by the longer, curved path **in the same time** as if it fell vertically to the ground. We can illustrate this fact by giving one of two marbles a horizontal blow (Fig. 92), while permitting the other to fall vertically from the same height.

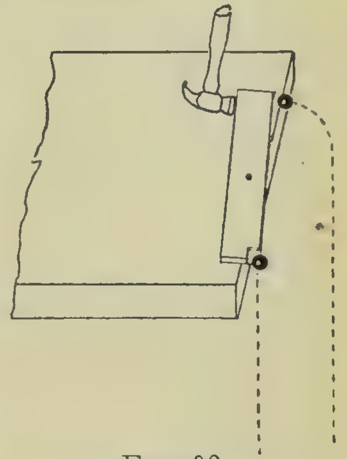


FIG. 92.
The two marbles reach the floor at the same instant.

111. Can a Body Start or Stop Itself?

— What happens when you are standing in a street car and the car suddenly stops? Your feet stop with the car, but your body goes on, and you fall forward. What happens when the car starts suddenly? You fall backward, do you not? When a car turns a corner, your body goes straight ahead, while your feet follow the car; hence you fall to one side. When some one rushes toward you at full speed, you spring aside or "dodge"; for you know that he cannot stop himself at once, but must go on *in a straight line.*

What is true of our bodies is true of every body of matter. A baseball or football cannot start itself; it must be thrown or kicked. It cannot stop itself, but must be stopped: by the *uneven* places of the *ground,* or by the *resistance* of the air, or by some one who catches it. If something starts it at a given rate of speed, it must keep on moving at that rate of speed and *in a straight line,* unless something else acts upon it. These illustrations show us that, besides having weight and occupying space, matter has another striking quality, or property: **helplessness.** Its usual name is **inertia** (ĭn-ĕr′shă).

There are many other common illustrations of inertia. When you shake a rug, you shake the rug away from the dirt, because of the inertia of the dirt. When you run around a corner, you go in a wide curve; you cannot turn the corner sharply, because of the inertia of your body. If you hit a suspended newspaper, you burst a hole in it; only the part struck moves forward; the main portion remains behind. You will realize that the air has inertia, too, if you try to push it away suddenly with a large fan, or with a newspaper fastened in a large hoop. The air remains where it was, and tears the paper, just as a rock or a tree would. Try to shut a door in a strong wind, or to "haul in" a sail in a gale, and you will realize the inertia of air in motion.

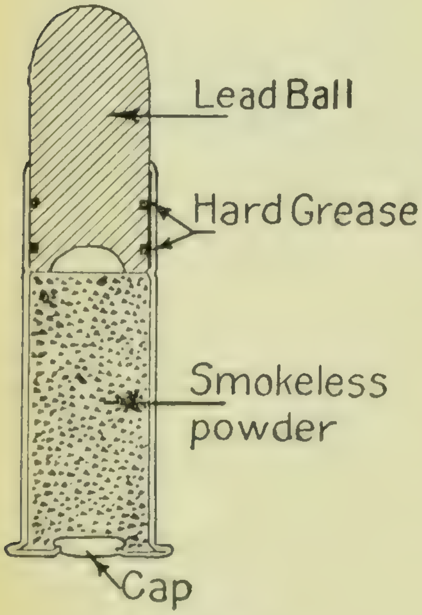


FIG. 93.

A cartridge, containing a lead ball, grease grooves, smokeless powder, and percussion cap. The hammer of the rifle dents the cartridge, exploding the contents of the "cap." This explosion ignites the powder; so that gases able to occupy about 300 times as much space as the powder are released. The expansion of these gases propels the ball.

112. What is a Force?—We may add other illustrations to those of § 111 to show that a body must be **set** in motion, if it is to move. A bullet's flight is due to the exploding powder in the cartridge (Fig. 93), which produces a large volume of **expanding gases.** An automobile tire "blows out" because the air we have compressed in it exerts a powerful **push.** In the "bow and arrow" we bend the bow, and as it straightens itself it drives the arrow to its mark.

What name can we give to a body that **gives motion** to another body, or **stops** the motion of another body, or **changes** the direction or velocity of the other body's motion? We call it a **force.** We say that one body **exerts force** upon another. We may also say that force is the **action** of one body upon another, in the form of a **push** or a **pull.** Thus we think of the pull between the earth, the moon, and the sun as due to the **force of gravitation.** When a pitcher throws a ball, or a horse pulls a load, the **muscular force** of the pitcher or the horse is causing motion.

Air exerts force both by pushing against bodies that pass through it; also as **wind,** which is air in motion. The force exerted by the air at rest makes it possible for a swiftly moving airplane to "fly" and a balloon to rise; while the force of moving air makes kites rise, windmills turn, and ships sail the seas.

The **resistance** which a body meets when it pushes its way through air or water, or along the ground, and which one part of a machine meets as it rubs against another part, is a very important force; we call it **friction.** What means are used to make the friction between the parts of a sewing machine or automobile as small as possible?

The force of expanding gases is exerted not only in setting a bullet or shell in motion, but in driving a steam engine and a gasoline engine. Steam having a pressure above that of the atmosphere is produced in a boiler and allowed to expand in the cylinder of the steam engine. The steam sets the pistons in motion. Automobiles, airplanes, motorboats, and many other machines, are driven by gasoline engines in which a mixture of gasoline vapor and air is exploded by a hot wire or an electric spark. The large volume of hot gases produced gives motion to the engine.

113. Why Do Objects Fly from the Center?—Have you ever noticed how mud flies off a revolving carriage or automobile wheel? It flies off *in a straight line.* Why is it that while the mud is attached, it revolves in a circle with the wheel; yet the instant it is free it flies off in a straight line? If you notice the direction of the line carefully, you will see that it does not come out from the *center* of the circle, but just touches the outside (circumference) of the circle (Fig. 94). Such lines are called **tangent** (tăn′jĕnt; touching) lines. How do water drops fly off from a revolving grindstone?

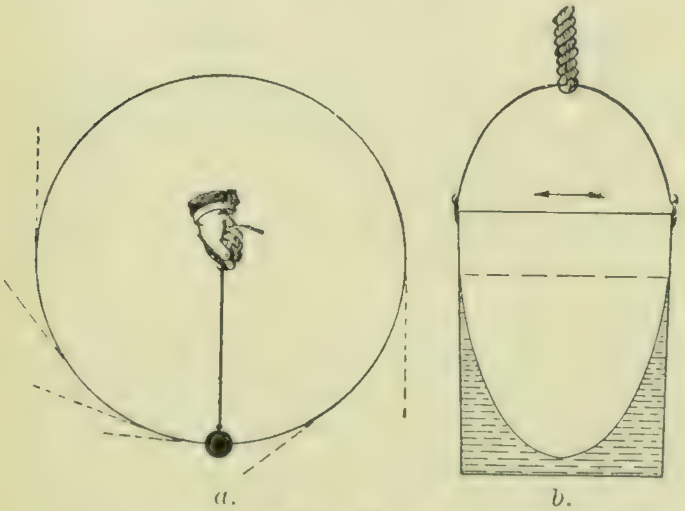
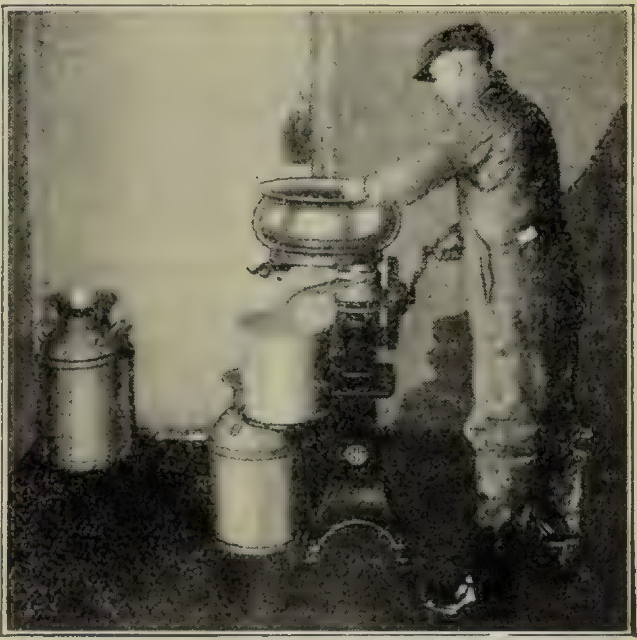


Fig. 94.

a. The ball moves in a circle because inertia, acting alone, would carry it forward in a straight line; while the string holds it always at the same distance from the center. *b.* As the pail is whirled by the untwisting of the rope, the water is piled up against the sides of the pail. Why?

If you attach a stone, or, better, a rubber ball, to a string, and whirl it about your hand, its path is a circle; but if you let go of the string, the stone or ball flies off in a straight line. If you hold on to the string, but revolve the stone more and more rapidly, the pull on the string becomes stronger and stronger. Finally the string may break.

This pull which a revolving body exerts in its effort to fly off in a tangent line is called the **centrifugal** (sĕn-trĭf′ū-g’l) **force** of the body, from words meaning "to fly from the center." You will see at once that it is not a new kind of force, but simply a result of the **inertia** of matter; a moving body **must** move in a straight line, unless some force acts upon it. The circular path of the revolving stone is the result of **two forces** acting at the same time: (1) the **inertia** of the matter of the stone, which acting alone would cause the stone to move in a straight line; and (2) the **resistance** of the string, which compels the stone to remain always at the same distance from the hand.



Courtesy of International Harvester Co.

FIG. 95.

The cream is separated from the milk by the rapid whirling of the machine.

Is any use made of centrifugal force? By revolving wet clothes in a **centrifugal drier** we can dry the clothes, because the water drops fly off. We can dry wet crystals of granulated sugar or salt in the same way. The **dairy separator** (see Fig. 95) is a machine for separating cream from milk by rapid whirling. Inertia causes the milk, which is the heavier, to move out farther than the **cream,** and so separates them. The **planets** (see § 156) are much larger than a stone that we can whirl with a string, but the reason why their paths, or **orbits,** are nearly round is much the same. Instead of a string there is the force of gravitation. If this acted alone, the planets and the sun would rush together, or, as we say, the planets would fall into the sun. If gravitation were to stop, the planets would move off in straight lines into space. But the two forces acting together: (1) the tendency of revolving matter to move off in tangent lines, and (2) the pull of gravitation, make the planets revolve about the sun.

114. Why Does a Pendulum Swing?— You may think you have seen a pendulum only in a large clock; but any object that is suspended and left free to swing to and fro is a **pendulum.** Recall the motion of a swing, a hammock, a sagging telephone wire. **Galileo** noticed that a lamp suspended from the ceiling of the Cathedral of Pisa swung regularly to and fro. By means of his pulse beats he found that whether the lamp swung out a long distance or a short one, the **time** of the swings was always the same. Because of this fact pendulums came to be used to tell time (Fig. 96).

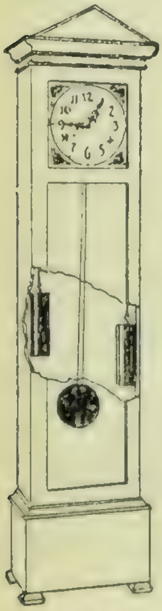


FIG. 96. A "grandfather" clock. Note the pendulum and the weights.

To-and-fro motion like that of a pendulum is called **vibratory** motion, and each swing of the pendulum from one end of its path to the other is called a **simple vibration.** The curved path taken by any point in the pendulum during a simple vibration is spoken of as the **arc** of the pendulum. If this path is $\frac{1}{6}$ of the distance around a complete circle, it is said to be an arc of 60 degrees; if it is $\frac{1}{18}$ of a circle, it is an arc of 20 degrees. How many degrees are there in a circle?

You can make a pendulum by hanging a weight, such as a piece of lead or iron, by means of a thread from a gas jet or other support. When at rest, the pendulum is a *plumbline.* Why?

If you draw it aside, it swings to and fro. Do you **lift** the weight when you draw it aside? Prove this by measuring the distance to the floor for both positions of the weight. Does the pendulum **fall** when you let go of it? What, then, makes a pendulum swing? It must be **gravity,** the earth's pull. The string that supports the weight alters the path of the falling weight, making it fall in a **curve,** instead of vertically (see § 110, last paragraph).

Make a pendulum with a string about 39 inches (1 meter) long, and count the number of simple vibrations it makes in 60 seconds. Then make a pendulum about 20 inches (half a meter) long, and count the number of vibrations in the same time. What is the effect of shortening the pendulum? If a pendulum clock runs too fast, how can you make it run more slowly?

What stops a swing when we "let the old cat die"? It is the rubbing (friction) of the rope against the points of support, as well as the resistance of the air which the swing and the person swinging must push out of the way. For the same reasons the arc of a swinging pendulum becomes smaller and smaller, until motion ceases.

Why does not a pendulum stop when it reaches the lowest part of its arc? In falling through one-half of its arc it has gained **inertia** of motion (see § 112); it cannot stop itself; hence it swings as far (except for friction) on the other half of its arc. We say that the pendulum has gained a certain **amount** of motion, or **momentum.** The momentum of a moving body depends not only upon its **mass,** but also upon its **velocity.** It is easy to catch a **tossed** baseball; harder to catch a swiftly **pitched** one; it would be harder yet to catch one **shot** out of a cannon. The mass of the ball does not change; but the difference in velocity makes a great difference in the momentum.

115. What is Energy?—What do we mean when we say that a person has energy? We mean, do we not, that he can **do work?** Energy means the same in science: the *capacity for doing work.* When we lift a hammer, we do work upon it, for we lift it against the action of gravity. It in turn can do work when gravity pulls it down: it can break a nutshell, or drive a nail. Is it easier, or harder, to drive a nail into the ceiling than into the floor? Why? We also do work when we throw a ball, or draw a bow, or wind up a watch. A body that can do work upon another body possesses energy.

While a hammer is poised in the air, it is not yet doing any work, but it has an *advantage* because of its *position*: we have done work upon it in lifting it. We say it has **energy of position.** So a rock at the top of a cliff, or water at the top of a waterfall, has energy of position. When each of these falls, its energy of position is changed to **energy of motion.**

A shell in a cannon at the instant the powder is fired can be said to have energy of position, because of the compressed gases behind the shell. In its flight the shell has energy of motion. When it strikes a rock or tree or other obstruction, it *does work.*

What kind of energy has a wound-up watch spring? A "grandfather" clock with its weight lifted? A bent bow? A stretched rubber band? A pendulum at the highest point in its arc? A tank of compressed air? How did each acquire its energy?

116. Work and Power.— A body of matter having energy (a **force**) does not actually *do work* unless it **moves** the body upon which it acts:

Work = Weight × Distance.

Thus, when a man or a machine lifts a weight against gravity, we obtain the amount of work done by multiplying the weight lifted by the vertical distance it is raised. A mason who carries 50 lbs. of mortar up a ladder 20 ft. high does 1000 (50×20) **foot-pounds** of work. A boy who walks 1000 ft.

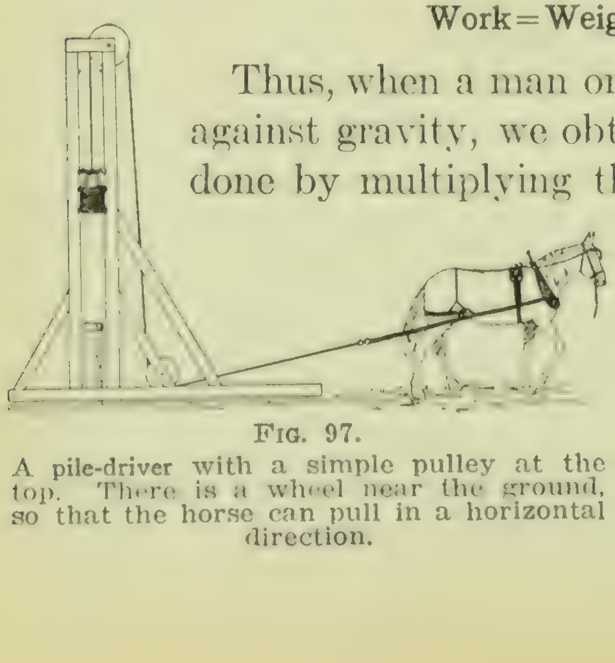
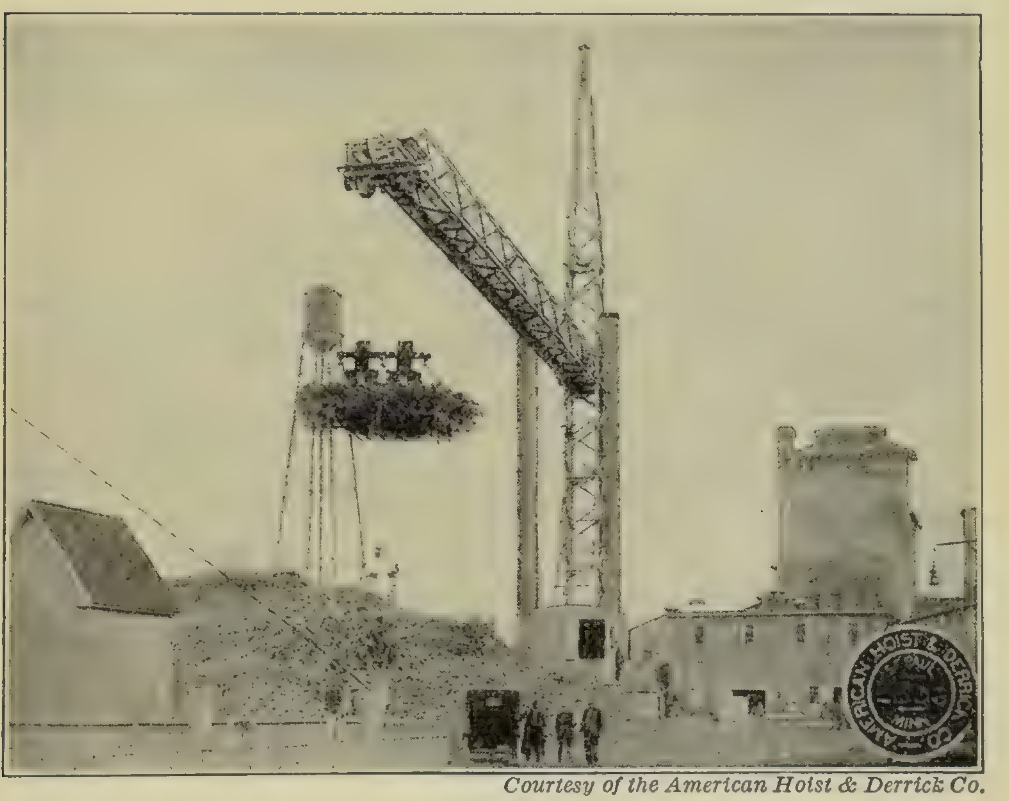


FIG. 97.

A pile-driver with a simple pulley at the top. There is a wheel near the ground, so that the horse can pull in a horizontal direction.

against a gale that presses against his body with a force of 50 lbs. does 50,000 foot-pounds of work.

Thus far, in considering the amount of work done by a force we have not considered the **time** required. But time is an important element in work. If we were choosing a horse (Fig. 97) or an engine (Fig. 98), to raise heavy weights, we would take the one that could do the work most rapidly. The rate of doing work is **power.**



Courtesy of the American Hoist & Derrick Co.

FIG. 98.

A powerful crane operated by electric motors. It can pick up 3 tons of sugar cane at a "grab."

The common **unit** of power is the **horse-power** (written H. P.). It was devised by James Watt. Watt thought that an average horse could raise 33,000 lbs. 1 ft. in 1 minute, or 550 lbs. 1 ft. in 1 second; consequently he called this amount of work a horse-power.

117. Exercises.— 1. Why does a locomotive begin to slow up long before it reaches the station?

2. If dropped from the same height at the same time, which will reach the ground sooner, a pound bag of feathers or one of nails? Why?

3. If a plumbline were hung beside a high cliff with vertical sides, would the plumbline hang straight down?

4. Why is it so hard to walk upon a polished floor? Why is it easier to skate upon ice than to walk upon it?

5. Why does not gravitation draw the sun and moon together?

6. The Great Pyramid was built about 2900 B. C.; what has become of the energy expended in raising it?

7. A horse pulls a ton (2,000 lbs.) of coal up a hill 50 ft. high; how many foot-pounds of work does he do upon it?

8. Put down your weight, and calculate how many foot-pounds of work you would do in climbing straight up a ladder to the top of a lighthouse 100 ft. high. Would the amount be the same, or greater, or less, if you walked up a spiral staircase?

9. On which will a marble roll farther, a carpet or a smooth floor? Why? Would there be any force to stop a rolling marble on a perfectly smooth, horizontal plane?

10. When you strike the lowest of a pile of blocks a sharp blow, it flies out, leaving the other blocks piled up. Why?

11. What happens to a child sitting on a sled, if the sled is suddenly started? If the moving sled is suddenly stopped? In what direction is the child thrown, if the sled turns a street-corner sharply? Why?

12. What work was done upon the water of a raindrop to give it energy? Upon a hailstone?

13. Why does a baseball pitcher have to "allow for the wind"?

14. Why is it dangerous for an automobile to turn a sharp curve at high speed? Is any device used on a road to make turns less dangerous? Is a similar device used on a running track?

15. What is a carpenter's or mason's "spirit level"? What force do we depend upon in using it?

16. Classify the kinds of forces named in § 112.

118. The Force in a Water Surface.— There are some properties of water so common that we rarely try to understand them; yet they are very important. We know that when we put objects into water, they generally become **wet.** We know also that when water falls in small masses, it forms **drops.** If we examine the surface of some water in a glass, we find that it is not perfectly level, but **creeps up** the sides of the glass. What force produces these results?

If we hold a sheet of glass down against a water surface, and then try to pull the glass away, we find that we must use more force than that represented by the weight of the glass; some force besides gravity is being exerted, and resists our tearing the glass away. Since the under side of the glass is left **wet,** we know that we do not tear glass away from water, but *water from water;* that is, we **break** the column of water under the glass. We can measure the breaking weight of the water better if we attach the sheet of glass to one side of a balance (Fig. 99), and then add weights to the other side until we tear the glass away.

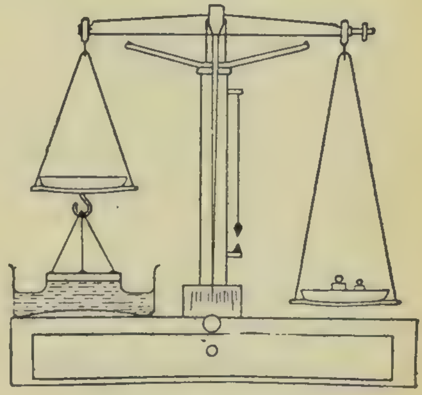


FIG. 99.
How we can determine the force needed to pull glass away from water. We are really tearing water from water. Why?

The force that holds the water particles together is called **cohesion.** When the force is exerted between *different* substances, we call it **adhesion.** So cohesion holds the particles of water together, and the particles of glass together, but adhesion holds water to glass. A postage stamp **adheres** to the envelop. Which is the greater force, the adhesion of water to glass or the cohesion of water?

Why do liquids form **drops?** Large liquid surfaces are horizontal, because gravity pulls down equally on all parts of the surface. But when the body of liquid is small (a **drop**), the effect of gravity is also small, and cohesion is able to pull the liquid into the shape of a sphere. The liquid surface acts like a tightly stretched, **elastic** covering, say, of rubber. That there is such an elastic surface is shown by an experiment in which we float a needle upon water (Fig. 100). We grease the needle slightly, so that water will not wet it, and then put it down carefully, by the aid of a fork, on the water's surface. We can see that the needle stretches the surface, but without breaking it. Is the needle heavier, or lighter, than water?

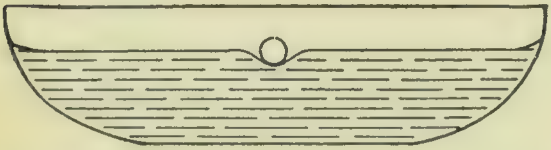


FIG. 100.
The greased needle stretches the water surface without breaking it.

The shape of a drop of liquid depends upon cohesion; but when there are **many** drops in a vessel the shape of the liquid surface depends upon **three** forces: (1) gravity; (2) cohesion of the liquid; and (3) adhesion between the liquid and the wall of the vessel.

If possible, examine the surface of some mercury in a glass vessel (see Fig. 15, § 15; also Fig. 101). Mercury does **not** wet glass. The cohesion of mercury must, therefore, be greater than the adhesion between mercury and glass. Hence the mercury surface **curves outwards,** or is **convex,** like the surface of a drop.

Since water wets glass, the adhesion between water and glass must be greater than the cohesion of water. In such cases the liquid is drawn up at the edges, and the surface **curves inwards,** or is **concave** (hollowed out). In a greased vessel water has a convex upper surface. Which is stronger, the adhesion of water to grease, or the cohesion of water?

119. Why Does a Blotter Absorb Ink?—If you touch a drop of ink with a blotter, the whole drop flows into the blotter. If you leave one end of a towel in water, the water rises, against gravity, into the towel. In watering a potted plant we often set the pot in a saucer of water, and the water rises into the pot. The work of raising the water in such cases is performed by the force called **capillary action.** "Capillary" means *hair-like*; capillary action is so called because it takes place in tubes of small diameter (Fig. 101).

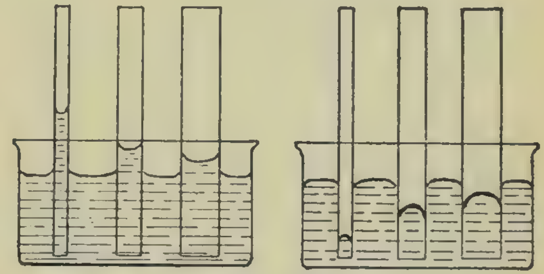


FIG. 101.

The elastic water surface lifts the water columns, against gravity, up into the tubes and around the sides of the dish. The mercury surface exerts force enough to depress the mercury.

What is the cause of capillary action? Adhesion and cohesion: adhesion between the water and the glass, and cohesion of the water, which produces an elastic surface. If we have the water in a dish, or in a large tube, the water is raised only at its edge. The elastic surface cannot exert force enough to raise all the water in the dish or tube. But if the diameter of the tube is small, the weight of the water in it is also small, and the elastic surface has force enough to lift the whole column of water up the tube. Water rises up between two plates of glass held close together, just as it does in small tubes. In the case of the blotter, towel, string, the earth of the flower pot, and other loose materials, the particles of the material are so close together that the spaces between them act like a multitude of fine tubes.

120. Why Does a Body Float?— If you lift a block of pine wood by a string attached to it, you must exert a muscular force equal to the weight of the wood; but if you rest the block on water, the water supports the block. We say that the block *floats* on the water.

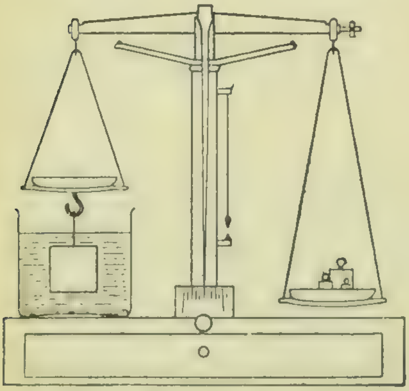


FIG. 102.
A solid body immersed in a liquid (or gas) is buoyed up by a force equal to the weight of the liquid (or gas) that it displaces.

Have you ever tried to lift a stone from the bottom of a pond or lake? If you have, you have probably been surprised to find that the stone seemed much heavier **out of** the water than in it. In the case of the floating wood the water supports **all** of the weight; in the case of the stone, or any other body entirely *immersed* (i. e. under water), the water supports only *part* of the weight. You have to make a greater effort in lifting the stone in air, because the water ceases to **buoy up** the stone.

Because of the **buoyant force** exerted by water, light bodies float, and any object weighs less in water than in air. This loss of weight is perfectly definite in amount. Suppose that you have a lead cube with a volume of exactly 1 cu. cm., and attach it to one arm of a balance (Fig. 102). It will weigh **1 gram** less in water than in air. One cubic centimeter of iron, copper, glass, or marble, or any solid which we can immerse in water, would lose the same amount: 1 g., when weighed in water. Since the 1 cu. cm. of water displaced by each of the cubes weighs just what each cube seems to lose, we decide that *a body under water is buoyed up by just the amount of water it displaces.* A mass of iron, lead, copper, stone, or glass having a volume of a *cubic foot* weighs 62.5 lbs. less in water than in air, since this is the weight of a cubic foot of water (see §§ 87 and 121).

You will see at once that we can make an **important use** of the facts regarding the buoyant force of water: we can easily obtain the **volume** of a solid body, **no matter what its shape.** We need only weigh the body in air and in water. We know that 1 cu. cm. of water weighs practically **1 gram** (§ 87). If, then, a body (regular or irregular) weighs 1 gram less in water than in air, its volume must be **one cubic centimeter.** If a stone is found to lose 62.5 lbs. when weighed in water, its volume must be **one cubic foot.** These facts help us directly in getting the **density,** or **specific gravity,** of solids (see § 121).

How far does a floating body sink into water? It sinks until it has pushed out of the way (**displaced**) its **own weight** of water. A piece of cork $\frac{1}{4}$ as heavy, volume for volume, as water, sinks until $\frac{1}{4}$ of it is below water. A piece of pine wood, $\frac{1}{2}$ as heavy as water, sinks halfway; a piece of ice, $\frac{92}{100}$ as heavy as water, floats with $\frac{92}{100}$ of its volume under water. Thus less than $\frac{1}{10}$ of an iceberg is above water.

A **steel ship,** or a steel pail, has walls made of material much heavier, volume for volume, than water; but it can float because it is able to push so much water out of the way. A **submarine** can be made to float when its air compartments are full of air (see § 11), and the boat as a whole is lighter than water. A **balloon** weighs less, volume for volume, than the air at the earth's surface, and when released rises, because of the **buoyant force** of the air.

What really causes bodies to sink or float? Is it not **gravity?** If you push a cork to the bottom of a pail of water, it bobs up again, because gravity pulls the heavier body (the water) as near as possible to the earth. The water then pushes up the cork. For the same reason, when we say that a balloon **ascends,** we mean that gravity pulls down on the air, and the air pushes up the balloon.

121. What is Density?— *Density* may seem like a new word, but the idea it represents is already a familiar one. You know what "dense" means as applied to a forest. A dense forest is one that is *compact;* with the trees close together; with a great many trees *in a given space.* In the same way we speak of a piece of lead as **dense,** or of "high density," because it has a great deal of matter in a small space, or volume. The **density** of a body, as we use the term in science, answers the question: How much matter, **by weight,** is there in a given volume, say, in 1 cu. cm., or 1 cu. in., or 1 cu. ft.? See Fig. 103.

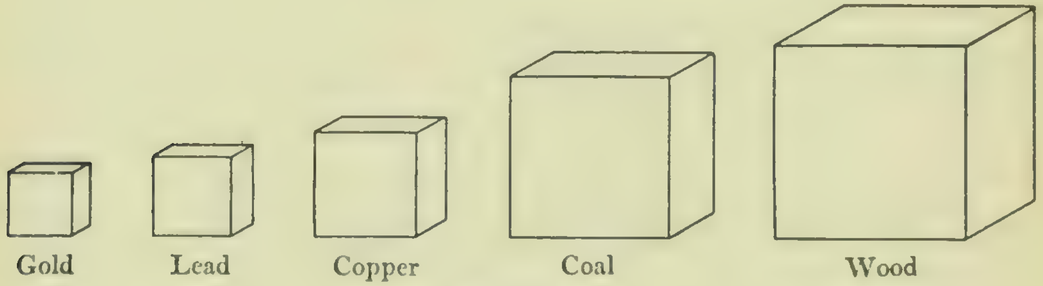


FIG. 103.

Cubes of these relative volumes contain equal weights of the materials named. Which is most dense?

Pure water at 4° C. has a density of 1 gram per cubic centimeter, and is taken as the **standard** for liquids and solids (Table III, Appendix). Its density is **1.** If 1 cu. cm. of glass weighs 3 g., the density of the glass is 3; it is 3 times as heavy as water. The general statement is:

$$\textbf{Density}\left\{\begin{array}{l}\text{in grams}\\ \text{per cu. cm.}\end{array}\right\} = \frac{\textbf{Weight}\text{ (in grams).}}{\textbf{Volume}\text{ (in cu. cm.).}}$$

If we use the English system instead of the metric, we say that water has a density of 62.5 lbs. to the cubic foot. From Table III we learn that iron has a density of 7.8. The weight of a cubic foot of iron must, therefore, be 62.5×7.8, or 487.5 lbs. What is the weight of 1 cu. cm. of iron?

The term "specific gravity" means much the same as density. It refers more directly to the way in which we actually get the density of a body. We need, of course, to know the **weight** and the **volume** of the body. How are we to find the volume? We might saw, or whittle out, a regular block of it, and calculate the volume from its length, breadth, and thickness. But this would be a difficult process. We learned, in the last section, an easier way of getting the volume of a solid, whatever its shape. The method is to find out how much, in grams, the body loses when it is weighed in water. This number represents the volume, in cubic centimeters, of the body. So the practical method of getting the density, or specific gravity of a solid, is to divide the weight of the body in air by the amount it seems to lose when weighed in water.

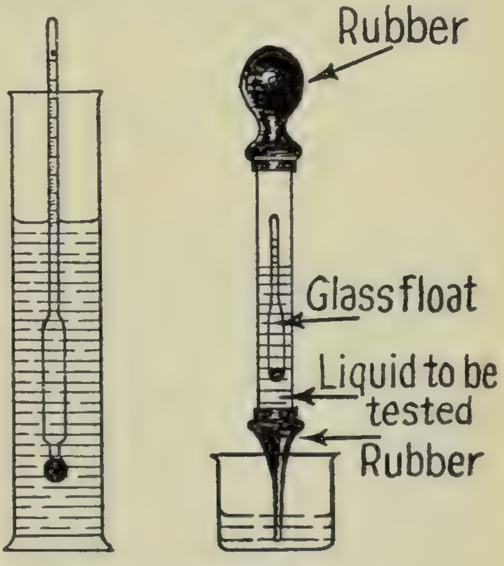


FIG. 103, *a*.
The hydrometer sinks in the liquid until it has displaced its own weight of liquid. We fill the syringe of the battery tester (on the right) with enough of the battery solution to float the hydrometer.

We can also use the behavior of a floating body as a means of getting the density of a liquid. We call the floating body used for this purpose a **hydrometer** (Fig. 103, *a*). The depth to which the hydrometer sinks in pure water is called 1 (usually written 1.000). If the liquid has a smaller density than water, the hydrometer sinks deeper than in water; if the liquid has a greater density, the hydrometer does not sink so far. The ordinary automobile **battery tester** is really a glass hydrometer made to float inside a syringe.

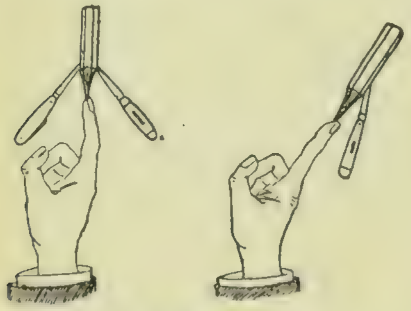


FIG. 104.
The pencil and knives assume such a position that the center of gravity is below the point of support.

122. Why a Body Stands or Falls.— Why does an egg or a top, if left free to turn, prefer to lie on its side? Why is it so hard to make a slender stick or pole stand upright? Everywhere we find illustrations of the fact that irregular bodies, such as tables, chairs, books, vases, lamps, dishes, and clocks, must be placed in certain positions, or they will fall over. An empty ship must be **ballasted,** or it is in danger of "turning turtle." If we wish to keep any body upright, we must see to it that the matter of the body is properly distributed (Fig. 104).

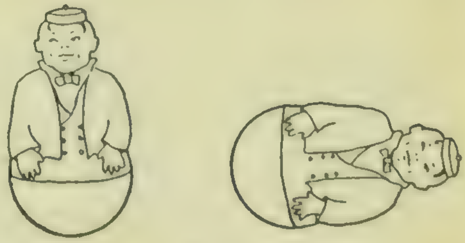
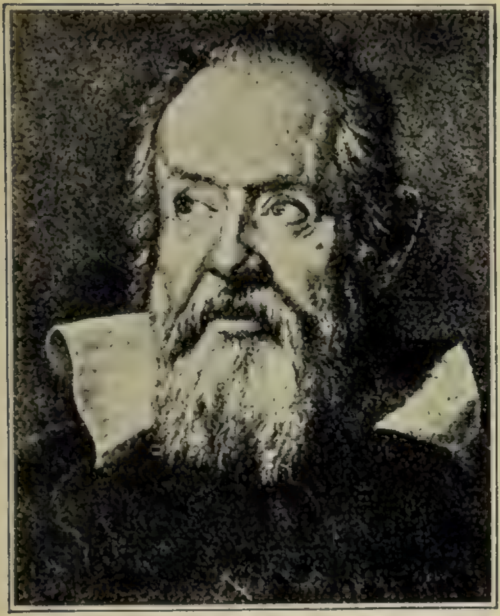


FIG. 105.
The lower part is of heavy material, while the upper part is of light material; hence the toy cannot be made to lie on its side. Why?

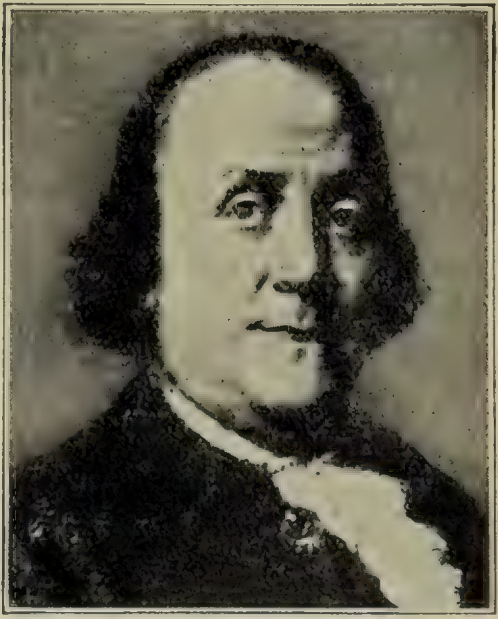
What is the **center** of a sphere? It is the point around which the **volume** of the sphere is arranged in a regular way. In a wooden ball or a lead ball the **matter,** as well as the volume, is all balanced around the center; hence we call the center of volume the **center of mass,** or **center of gravity,** of the ball. If we place such



GALILEO (1564-1642).
Discoverer of laws of falling bodies and pendulum.

SIR ISAAC NEWTON (1642-1727).
Discoverer of laws of gravitation and motion.

WILLIAM HARVEY (1578-1657).
Discoverer of the circulation of the blood.



BENJAMIN FRANKLIN (1706-1790).
Proved identity of lightning and frictional electricity.

a ball on a smooth, horizontal surface, it will lie in any position, because all of the matter in the ball is evenly distributed about its center. But suppose a ball is half wood and half lead. The ball will lie in only one position, with the lead below. The center of mass will be somewhere in the lead half of the ball.

You have played with the toy "tumbler" that will not lie on its side (Fig. 105). In the "cootie" games the **cootie** consists of a light capsule, of some material like celluloid, and, on the inside, a grain of shot. As the shot rolls inside the capsule, the center of mass is **shifted,** and the toy, instead of moving in the direction in which it was started, makes irregular, haphazard movements.

A body is able to stand when we can keep its center of mass above the base on which the body rests. But a body stands best, or is most **stable,** when the center of mass is in the **lowest** position possible. We ourselves can stand only when we keep the center of mass of our bodies directly above our feet. An egg lies on its side because in this position its center of mass is lowest.

123. Summary.— **Gravity** is the earth's pull upon bodies at or near its surface. **Gravitation** is the attraction existing between all bodies of matter.

The **mass** of a body is the quantity of matter in it.

The **weight** of a body represents the earth's pull, at a given place, for the mass of the body.

The **amount** of attraction between two bodies depends upon the masses of the bodies and the distance they are apart.

A body **weighs** more at the earth's poles than at the equator, and more at the surface than above the surface. The **mass** does not change.

The earth's pull is **vertical,** in the direction of a plumbline.

In a **vacuum** all bodies fall with the same speed.

If a **falling** body is acted upon by a **horizontal** force, such as the wind, its path is curved; but the time taken is the same as if **gravity** acted alone.

Force is the action of one body upon another. Force is exerted by the muscles of men and animals, by the earth, by air, by expanding gases, by other bodies (as resistance and friction).

No body can move itself, or stop its own motion, or alter its velocity, or change its motion from a straight line. This helplessness of matter is called **inertia.**

Centrifugal force is the pull of matter, when revolving, against whatever prevents it from moving in a straight line.

A **pendulum** swings from its highest position to its lowest because of gravity; from its lowest position to its highest position because of its inertia.

Energy is the ability to do work. There is energy of **position** and energy of **motion.**

Work (against gravity) = weight × vertical distance. Its unit is the **foot-pound.**

Power is the rate of doing work. Its unit is the **horse-power.**

The force that is exerted between **particles** of matter and holds matter together is called **cohesion,** or **adhesion.**

Cohesion causes liquids to form **drops** and to have **elastic surfaces.**

If a liquid **adheres** to a vessel, its upper surface is **concave.** If not, its upper surface is like a *flattened drop,* or **convex.**

Capillary action is the rising of liquids in narrow spaces or tubes. It is due to cohesion of liquids and their adhesion to solids.

The **density** of a body is the quantity of matter in a given volume. Pure water at 4° C. has a density of 1.

Buoyant force is the supporting, or lifting, power of liquids and gases.

A **floating** body is entirely supported. An **immersed** body is supported with a force equal to the weight of the liquid (or gas) it displaces.

The **center of mass** of a body is the point about which the matter of the body is balanced. A body can stand, or is in a **stable** position, when its center of mass is directly over some part of the base on which the body rests. It is most stable when its center of mass is in the lowest possible position.

124. Exercises.— 1. Why is a slender vase or lamp made heavy at the base?

2. Why is it possible to ride a bicycle and not fall to one side?

3. What force is overcome when we drive a nail into wood?

4. Why do water, mercury, and other liquids form drops? Why does a drop of mercury remain spherical on a table, while a water drop does not?

5. Why does a steel ship float?

6. Name the following substances in the order of their densities, beginning with the lightest (see Table III, Appendix): iron, cork, gasoline, lead, paraffin, aluminum, marble, zinc, copper, gold, silver, diamond, water, alcohol, and milk.

7. Why does not the leaning tower of Pisa fall over?

8. Is it easier to swim in fresh water, or in salt water? Why?

9. If 1 cu. ft. of water weighs 62.5 lbs., how much does 1 cu. ft. of lead weigh?

10. How does a life preserver attached to your body alter the **weight** that must be supported by the water? How the **density?** Why?

11. Why is it so hard to dry the hands on a new, unlaundered towel? Why is writing paper "filled" or "sized"?

12. We can find the volume of an irregular stone if we weigh it first in air and then in water. Explain how.

13. An iceberg may turn over after some of the part under water has melted away. Why?

14. How do you lean your body when you carry a heavy satchel? When you run forward? When you climb a hill? When you come down? Why?

15. Which is the most stable position: standing, sitting, or lying down?

16. Why can an egg with a dent in one end be made to stand upright, while one with a perfect shell cannot?

17. Why can you throw a stone with greater force from a sling than with your arm alone?

18. Can you make the expression "as heavy as lead," still stronger by substituting some other metal for "lead"?

125. Projects.— 1. Construct a plumbline, and with it determine if the walls of your school building and house are vertical.

2. Use a plumbline and a carpenter's or mason's square to find out if the floors and window sills of your room are horizontal.

3. With a carpenter's or mason's spirit level determine the facts of Projects 1 and 2.

4. Demonstrate the operation of a "cootie" toy to the class.

5. Bring an uncooked egg and a hard-boiled one to the class, and demonstrate which is which by the behavior of each when you try to spin it on its small end.

6. Make a toy tumbler from a round-bottom flask by putting some shot into the bottom of the flask, and filling the remainder with cotton batting. Demonstrate it to the class.

7. Have a carpenter drill a hole halfway through a wooden ball, such as a croquet ball, and plug the hole with iron or lead. Demonstrate its behavior when rolled slowly on a smooth horizontal surface.

8. Ballast a slender bottle with shot or sand until it floats upright. Could this be used for a hydrometer? See § 106, Project 14.

9. Prepare a report on the construction of coal and hay scales.

10. Prepare a set of samples of different materials used to diminish friction, and tell the class of their composition.

11. Prepare some pieces of apparatus to show the inertia of air at rest and in motion.

12. Find a centrifugal drier in a house or laundry in your neighborhood, and report its construction to the class.

13. Construct a pendulum of such length that it will swing 60 simple vibrations in 60 seconds. Then construct one that will swing 120 to the minute, and another that will swing 30 to the minute. Report the lengths, from point of suspension to center of bob, to the class.

14. Prepare a list of the horse-powers of as many kinds of locomotives, stationary engines, electric motors, and airplanes as possible.

15. Study the construction of curves in concrete and other graded roads, in railroads, and in running tracks. With a spirit level and a rule find how much higher one side of a running track is than the other.

16. Compare the breaking weight of water, molasses, and kerosene. See § 118. Use a sheet of glass of about 3×3 in., and fasten three strings to the glass by means of sealing wax. See that the glass is perfectly clean each time, and that it hangs in a horizontal position.

17. Determine the volume of a drop of water, in fractions of 1 cu. cm., by counting the number of drops in 5 cu. cm. or some other convenient volume. Determine the weight of a water drop in the same way.

18. Float needles of different sizes upon water. See § 118.

19. Demonstrate the shape of a drop when free from the walls of a dish. Into a slender bottle or a test tube put a tablespoonful of denatured alcohol, then a drop of olive oil, or of some corn oil such as *Mazola*, and finally add a tablespoon of water.

20. Determine the amount of water which a weighed amount of reasonably dry earth packed into a flower pot will absorb. SUGGESTION: Use a saucer to hold the water.

21. Prepare a set of samples of different kinds of paper, and demonstrate the effect of writing upon each with ink.

22. Demonstrate to the class that the loss in weight of an immersed body is equal to the weight of the water displaced by the body. SUGGESTION: Use an object of regular shape, so that you can readily compute its volume.

23. Demonstrate to the class the method of getting the specific gravity of a liquid by means of a hydrometer and an automobile battery (liquid) tester.

24. Demonstrate to the class the way in which an irregular floating object prefers to assume a definite position, and explain why.

126. References.— BARBER: *First Course in General Science.* LYNDE: *Physics of the Household.* MILLIKAN AND GALE: *A First Course in Physics.* TOWER, SMITH, TURTON, AND COPE: *Physics.*

CHAPTER IX

THE WEATHER

127. What is Weather?— No topic of conversation is so common as the weather. We ask: What is the temperature today? Is the air dry, or moist? Is the sky clear, or cloudy? Will there be dew or frost, rain or snow? Is there a strong wind, or a gentle one, and in what direction is it blowing? All these matters are very important to us, because they have so much to do with our plans and our comfort. Inside our houses we try to control the condition of the air, but out of doors it largely controls us.

The weather also attracts our attention because it is continually changing, apparently without any cause. Hence the expression: "changeable as the weather." We shall understand the weather better if we realize that we are living at the bottom of an **ocean of air** (perhaps 200 miles deep), and that the weather of the place where we live is the condition of only a very small part of the atmosphere. If we study the weather of the country as a whole, we shall see that the changes which seem so haphazard and fickle are really parts of great air movements. So there is a cause for every change, even of the weather.

As we look over the list of weather conditions, we see that they are really the conditions of **two materials** of the atmosphere: (1) the ocean of **air**; (2) **water**, which enters the atmosphere (as vapor) by evaporation from the wet land, and from rivers, lakes, and the sea, and which separates again in the liquid or solid form, as clouds, fog, rain, snow, dew, frost, and hail. The average of the weather conditions of any place is the **climate** of that place.

128. Why Weather Changes.— What takes place in air to cause weather changes? We can group the causes under three heads: (1) The atmosphere takes up heat, or loses it; (2) The atmosphere takes up water, or deposits it; (3) The density of the atmosphere is changed, so that a mass of heavier air pushes away a mass of lighter air. This change produces air currents and winds.

The **final source** of the heat of the earth's surface is the **sun** (see §§ 50 and 152). The sun's rays that come to us give up part of their heat directly to the atmosphere as they pass through it; but by far the larger part of their heat reaches the earth's surface. This portion is partly absorbed by the earth and partly reflected back (see § 204) into the atmosphere and into space. The heat absorbed warms the land and water for a time; afterwards it is given back to the air. Altogether about 70% of the heat received from the sun is probably taken up by the atmosphere. Of course this absorption is only for a time; for in the end the quantity received and the quantity lost are practically the same.

The lower part of the atmosphere absorbs heat much better than the upper part, and therefore becomes warmer. The reasons for this are that the lower air is more compressed, or dense (see § 16), and has more heat-absorbing materials in it, such as dust, smoke, clouds, carbon dioxide, and water vapor. These good absorbers make the atmosphere a **trap** for the sun's energy; they act as a **blanket** to prevent too rapid heating and cooling of the earth's surface (see § 131; also § 214).

Air, like other gases, is heated when it is compressed, and cooled when it expands (see § 96). As air ascends from the earth's surface, it expands; it therefore becomes colder. When the cold, upper air falls to lower levels, the opposite effect is observed: the air is compressed, and therefore becomes warmer. Thus the cold air that tumbles down the steep slopes of the Alps into the Swiss valleys is often changed into a hot wind (the *foehn*) because of its own compression.

129. Moisture of the Air.— Water changes into water vapor (evaporates), and the water vapor, like any other gas, mixes, or diffuses, itself with the gases of the air (see § 86). Even ice evaporates slowly, producing water vapor. We need not think of the air as a great sponge, or piece of blotting paper, that absorbs the water until it can hold no more. The scientist thinks of evaporation rather as a movement of the molecules **away from** the surface of the water or ice and **into** the surrounding air or space. The molecules of water fly off, like those of any gas, because they have sufficient **energy** (see § 115). Adding heat causes an increase in the energy of the molecules; hence warm water evaporates more rapidly than cold water.

In the open air the amount of evaporation seems to have no limit; because drafts and winds constantly bring new portions of air over the water and carry away the air that has already taken up water vapor; but in an **enclosed** space only a limited amount of evaporation can take place (see Fig. 106). At first water evaporates rapidly into the space, but after a time the amount of water vapor in the space becomes no greater, no matter

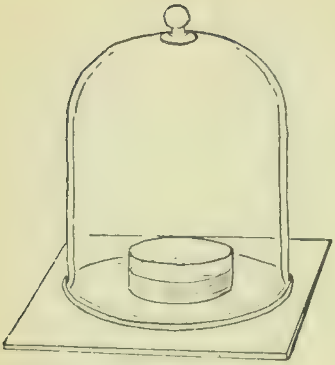


FIG. 106.
Liquid water set in an enclosed space saturates the space with water vapor.

how long the apparatus stands. The water does not cease evaporating, but its vapor is condensed to liquid water as rapidly as the liquid is changed to vapor. We say that the space (or air) is **saturated** with water vapor. If we raise the temperature, the space becomes unsaturated, although it was saturated at the lower temperature. More water will, therefore, change to vapor and mix itself with the air of the jar. But if we lower the temperature of the saturated space, enough of the water vapor will condense to leave the space just saturated at the lower temperature.

Like the other gases of the air, water vapor has **pressure.** At the ordinary temperature this pressure is small (see Appendix, Table VIII); but as the temperature of water rises, its vapor has a greater and greater pressure, until at 100° C. (212° F.) the water vapor (steam) has the same pressure as the standard pressure of the atmosphere, 760 mm. (see §§ 16 and 87). The steam then sweeps the air completely out of the vessel in which the water is being heated; we say the water is **boiling.**

130. The Humidity of the Air.— We have already learned (see §§ 76 and 77) that the amount of moisture in the air, that is, the **water vapor** mixed with the other gases of the air, has a great deal to do with our health and comfort. The amount of water vapor, by weight, in a given volume of air we call the **humidity** of the air. Tables giving the humidity (see Appendix, Table IX) usually state it as so many *milligrams* to the liter, or so many *grains* to the cubic foot. Thus a liter of air or space at 10° C. (50° F.) is saturated when it contains 9.33 mg. of water vapor; at 27° C. (80.6° F.) it can hold 25.49 mg. The cubic foot saturated at 10° C. with 9.33 mg. of water vapor is unsaturated if we warm it to 27° C. without adding more water vapor. It has, as a matter of fact, only 9.33/25.49, or 36.6%, of the amount needed to saturate it at 27° C.

The amount of water vapor actually present in a given space is called the **absolute humidity.** In the last paragraph the 9.33 mg. per liter at 10° C. is the absolute humidity at that temperature. This amount, divided by the amount the space would hold if it were saturated, gives the **relative humidity.** In the case named, the relative humidity is 36.6%. It is the relative humidity that has most to do with our health and comfort. Why? See § 76. If the relative humidity is low, say, 30% to 40%, the air feels dry; if the relative humidity is high, say 75% to 85%, the perspiration does not evaporate well, and the air feels "close," or "muggy." A relative humidity of 45% to 60% is usually most comfortable.

131. Dew and Frost.—We have been thinking of humidity as it affects our bodily comfort; let us now consider its relation to the formation of dew and frost.

You have seen a glass, or pitcher, possibly a tank, of cold water "sweat" on a hot day. Possibly you thought the water leaked out in some way. The truth is that the drops of water are formed by the condensation of the water vapor of the air upon the cold object; they are really **dew.** The temperature to which air must be cooled so that it will just deposit moisture is called the **dew point.** If the dew point is below 0° C., *frost* is formed instead of dew.

We can determine the dew point by a simple **experiment** (Fig. 107). Partly fill a deep, polished, metal cup or beaker with water at the temperature of the room, and add small pieces of ice to it, one at a time. Add a new one only after the one before has melted. Stir the ice and water with the bulb end of a thermometer, noting carefully when the first droplets of dew collect on the outside of the metal vessel. Then read the thermometer. The temperature you find is the dew point of the air at that time.

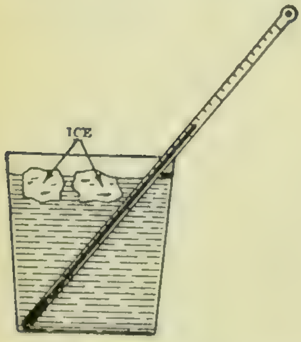


FIG. 107.
The iced water cools the air until it deposits moisture on the outside of the metal cup. The temperature shown by the thermometer is the "dew point."

In Nature, dew is commonly formed after sunset, when the air and bodies near the ground radiate their heat (see §42) and grow cool. Stones, grass blades, the roofs of houses, and other objects cool more rapidly than air, and their temperature falls below that at which air is saturated with water vapor. They therefore cool the air near them, so that it deposits moisture.

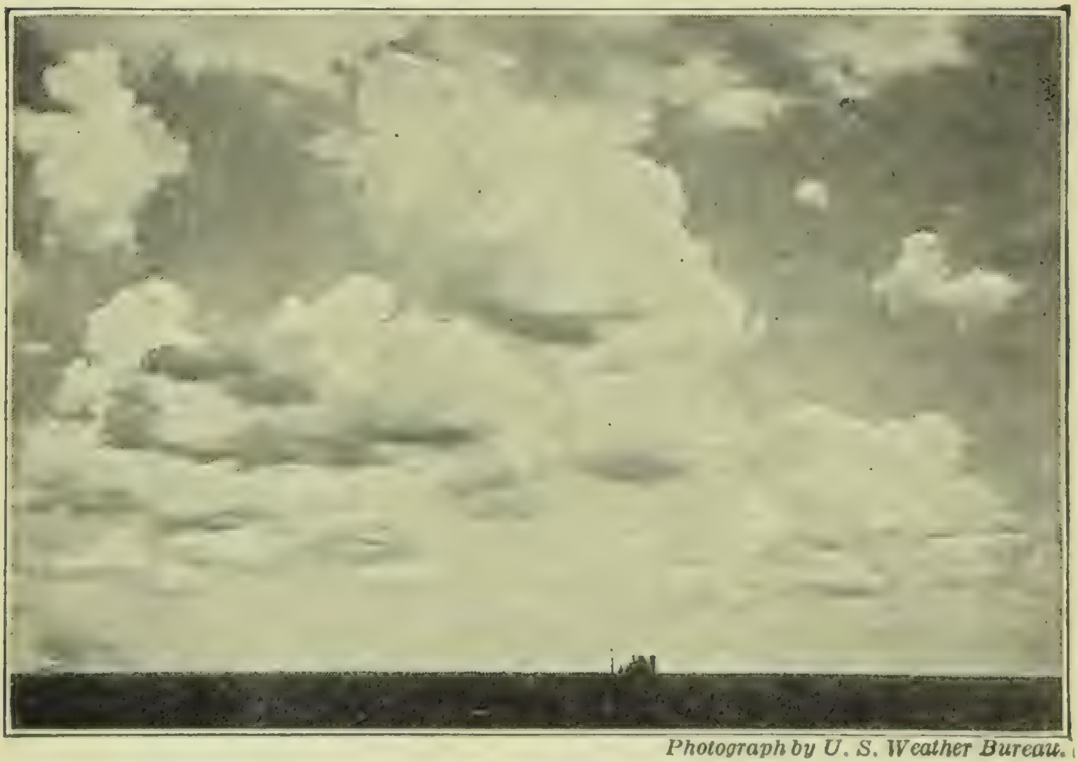
A **clear** night favors the forming of dew and frost; because the earth and the air cool more rapidly when clouds are not present (see § 128). A **gentle** breeze also favors it, because the moving air brings fresh supplies of water vapor to the cool objects. A strong wind is not favorable, for it does not allow the air to remain long enough in contact with the cool objects.

Experienced fruit growers know that they must provide **air drainage** as well as water drainage in their orchards. If an orchard is planted in a hollow, cold air will collect in it as water would, and may cause a damaging frost; while neighboring orchards situated on the slopes or tops of hills may escape injury.

We can use the dew point to determine the **relative humidity** of the air. Why would this be valuable in a greenhouse? In a schoolroom? In your own house? Suppose the temperature of a room is 23° C. In the Appendix, Table VIII, we find that the pressure of water vapor (see § 129) at 23° C. is 20.9 mm. This would be the pressure of the water vapor in **saturated** air at 23° C. Suppose that we find the dew point is 10° C. Table VIII shows that at 10° C. the pressure of water vapor is 9.1 mm. The air of the room has, therefore, less than half its capacity of water (9.1 divided by 20.9 gives 0.44, or 44%, the relative humidity).

132. How are Clouds Formed?— In § 128 we learned that one of the causes of weather changes is that the atmosphere takes up water, or deposits it. The formation of dew and frost is an illustration of this; so is the formation of fogs and clouds. If the air in contact with objects is cooled below the dew point, dew or frost is deposited; if the air *just above* the ground is thus cooled, its water vapor is condensed in tiny droplets, and we have a **fog**. When a fog is formed some distance above the earth's surface, we call it a **cloud**. Some clouds consist of **ice** particles.

Fogs and clouds are not permanent, but may disappear if the temperature of the air is raised above the dew point, as it often is by the rising sun. But even while a cloud lasts it is both losing droplets by evaporation and gaining them by condensation. Do you think that clouds are lighter than air, and float in the air? This is not so; cloud particles are heavier than air, and settle slowly toward the earth. But as they reach a layer of air unsaturated with water vapor, that is, **above** the dew point, they evaporate and disappear. This level, above which condensation takes place and below which evaporation is complete, is the bottom of the cloud. Clouds also extend **outward** until their water particles evaporate as rapidly as they are condensed. It is because cloud material is constantly being formed at one place and disappearing at another that clouds change their forms so readily. No one who has watched carefully the forming of thunderclouds on a sultry afternoon can doubt that they are really "springs" of water mist, that rise into the upper air, and then fall again in great, billowy masses.



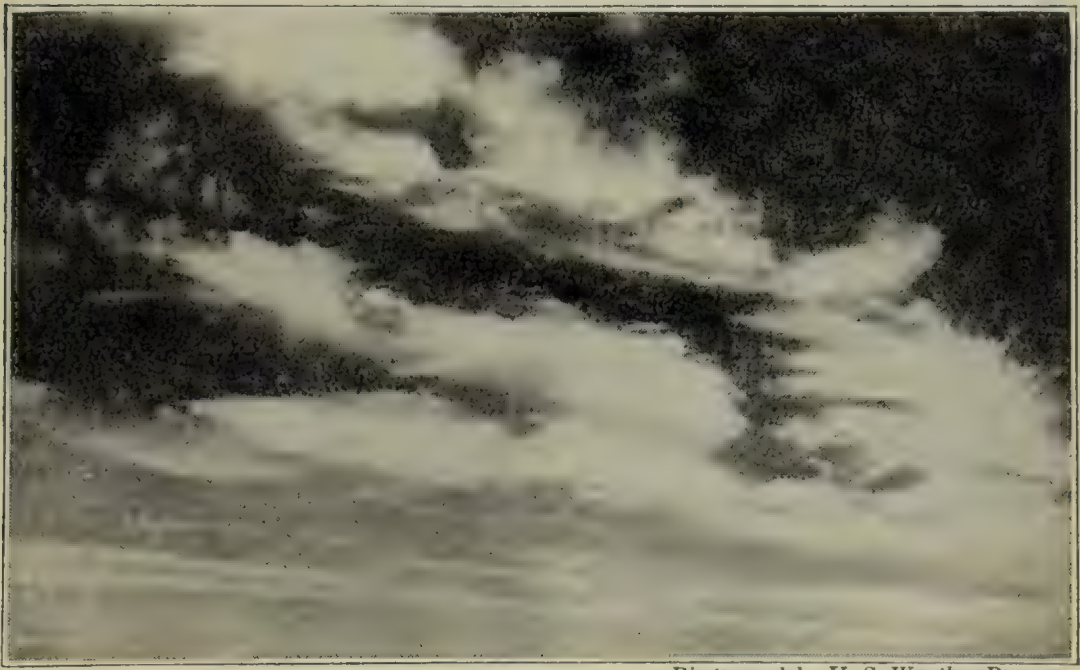
Photograph by U. S. Weather Bureau.

FIG. 108.
Cumulus clouds, Topeka, Kansas.

133. Cloud Forms.—Observe the clouds carefully and see how wonderful they are, and how many different shapes they have. We generally distinguish **four** principal forms:

(1) **Cumulus clouds** (Fig. 108), are so called from the Latin word for "heap," because they are rounded like heaps of wool. Our word "accumulate" has the same origin. Cumulus clouds are formed by ascending air currents laden with water vapor. They are commonly seen on warm summer afternoons, at a height of 1 to 5 miles, and often bring on thunderstorms and showers.

(2) **Cirrus clouds** (Fig. 109). Cirrus is from a word meaning "feather." These clouds are made up of distinct **lines.** The lines may be arranged in many strange forms, such as plumes, hazy streaks, and delicate wisps. One arrangement is called a "mackerel sky." Cirrus clouds are the **highest** of all; they are probably from 5 to 10 miles high, and consist of minute particles of ice or snow. They are often the forerunners of rain or snow.



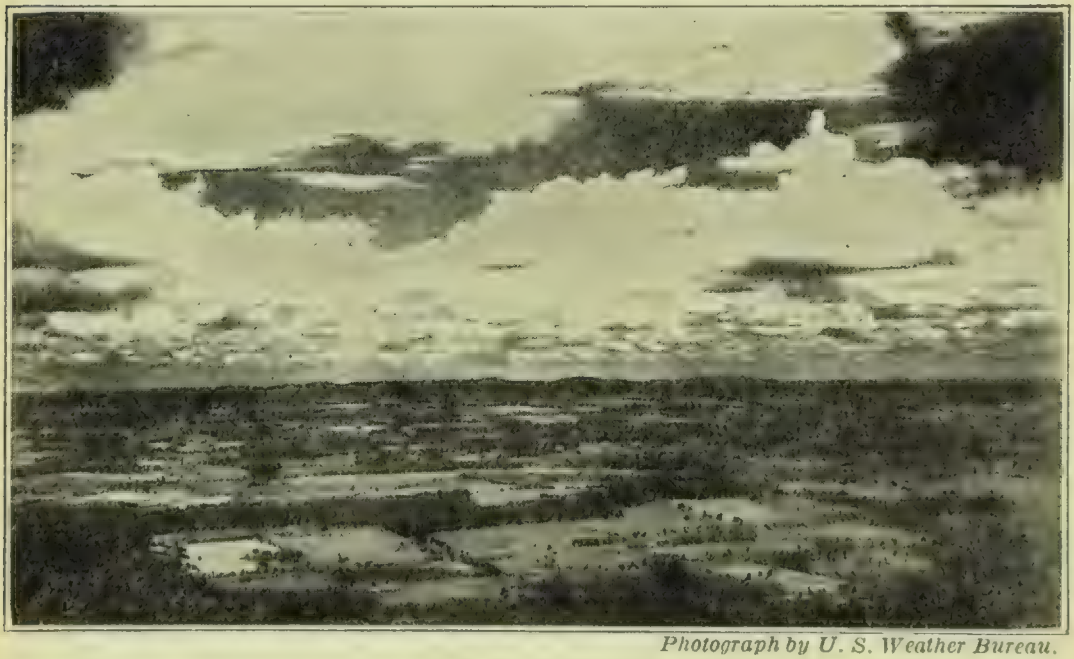
Photograph by U. S. Weather Bureau.

FIG. 109.
Dense, bunched cirrus clouds, probably of thunderstorm origin.

(3) **Stratus clouds**; so called because they occur in *layers* (Fig. 110). They are lower than the other two; usually from half a mile to 3 miles high. They sometimes reach down to the earth's surface, as fogs

(4) **Nimbus clouds**; these are so called from *nimbus*, a veil. Nimbus clouds are cumulus or stratus clouds from which rain or snow is falling.

There are also many combinations of cloud forms, such as cirro-stratus, cumulo-stratus, and cirro-cumulus clouds.



Photograph by U. S. Weather Bureau.

FIG. 110.
Cumulus and strato-cumulus clouds below, thin stratus clouds above. Mt. Weather, Virginia.

134. Rain, Snow, and Hail.— When the particles of water mist that make up a cloud gather together in **drops**, they fall rapidly. If they reach the surface before evaporating, we have **rain**. If the condition of the air is right for a rain, but the temperature is below 0° C., we have **snow**. How different rainstorms are! Sometimes the rain falls in tiny drops, at other times in great splashes. Snow is often made up of tiny, hard grains, at other times of single, perfect crystals of exquisite form (Fig. 84), and again of large, fluffy masses.

If the ascending currents of moist air are very strong, as they are in thunderstorms, tornadoes, and waterspouts (see § 140), an enormous quantity of water may be accumulated in the cloud. When this falls, we call the rain a **cloudburst.**

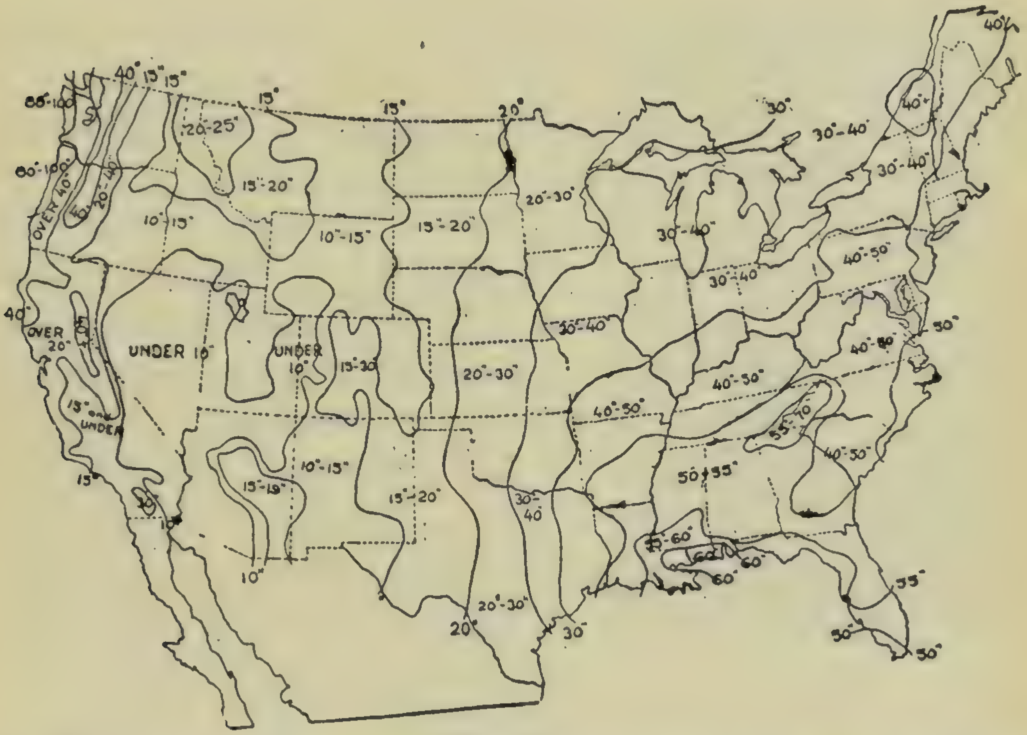
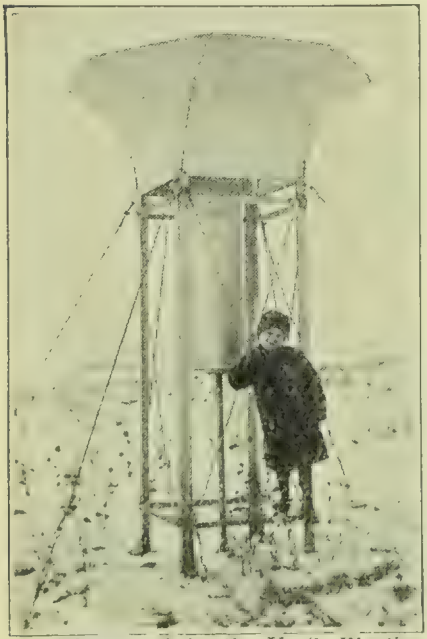


FIG. 111.
The figures show the average yearly rainfalls in the different regions of the United States.

Hail is made up of pellets or "stones" of ice or snow or both, arranged in layers. Hailstones probably begin in the freezing of raindrops at lower levels. These are carried upward, by powerful ascending air currents, through layers of air saturated with moisture; then they are dropped part way, and carried upward again; this treatment is repeated many times. Thus the stones take on layer after layer, until they become too heavy to be supported any longer, and fall to the ground. Hail does a great deal of damage, not only to window panes and roofs, but also to fruit trees and crops.

135. Rainfall.— Rain is so necessary for crops that its amount is of the greatest importance. If you examine a rainfall map of the United States (Fig. 111), you will find that one region gets less than 10 inches of rain in a year; another, 60 inches; and a third, even 80 to 100 inches. Before such a map could be made, the rainfall had to be measured for many years.



Photograph by the U. S. Weather Bureau.

FIG. 112.
The Marvin shielded rain and snow gauge.

Rain is caught for measurement in a **rain gauge** (Fig. 112). This is a funnel with a long stem. The opening of the funnel has exactly 10 times the area of a cross section of the stem, so that $\frac{1}{10}$ of an inch of rainfall gives a depth of 1 in. in the stem. The greater depth of water in the stem makes the reading more accurate. **Snow** is measured as rain, the snow being allowed to melt. About 10 in. of snowfall equals 1 in. of rain; but the proportion is not always the same, since snow falls in so many different degrees of wetness.

There are several **rules,** or **laws, of rainfall,** that scientists have found true:

(1) Rainfall is less in the interior of continents than on the coast. The amount for each continent depends on how far rain clouds can penetrate before a mountain barrier or plateau condenses their moisture.

(2) The greatest rainfall occurs in the tropics. This is due to the large amount of water vapor that can exist at high temperatures

(see Appendix, Tables VIII and IX) mixed with the other gases of the air.

(3) When rainfall takes place on mountain slopes, the sides get more than the base, for the reason that the moist air currents which bring the rain must go up the slopes some distance before they are chilled enough to give their greatest deposits.

Can you suggest how the rules just given hold true in the following cases? No regions are absolutely rainless, but half the earth's land surface gets less than 20 in. of rain a year, and is, therefore, considered unfit for farming without **irrigation.** The rainfall in Florida and on the Gulf coast is over 60 in. a year. The sea coast of the state of Washington has up to 100 in. These abundant rains are brought by warm, moist, ocean winds, which are cooled as they pass over the land. In the Plains Region, just east of the Rockies, the mean annual rainfall is below 20 in.; in the Nevada Desert, just east of the Sierras, it is less than 5 in.

The greatest rainfall in the world is in India, where the average of some regions is nearly 500 in. a year. How many feet is this? This enormous amount is brought by the southwest winds (monsoons) from the heated Indian Ocean, as they ascend the land to the tops of the Himalayas. Beyond the mountains the monsoon is not a wet wind, but a dry one, and the plateau of Thibet, over which it passes, is largely a desert.

136. Exercises.— 1. Describe the climate of your region.

2. Does the color of the soil have anything to do with the amount of heat it can absorb? Why does the snow under specks of dirt melt more rapidly than the clean snow beside it? Why does snow under a heap of dirt melt so slowly?

3. Why does a high mountain top exposed to the sun become very much hotter in the daytime than land in the valleys, but at night very much colder?

4. A balloon that is at a certain height during the night usually takes a sudden leap skyward at sunrise. Explain why.

5. Why does covering a plant at night prevent it from being frost-bitten? Why does a smudge protect an orchard from frost?

6. Suggest why a fog is formed more readily in a smoky atmosphere than in a clear one.

7. Why is the seashore of a country cooler in summer and warmer in winter than the interior? Review § 98, Chapter VII.

8. Is there any difference in meaning between the expressions: "air saturated with moisture" and "air at the dew point"? What is the relative humidity, in per cent, of air at the dew point?

9. About how many milligrams of water vapor are there in a liter of saturated air at 20° C.? At 0° C.? At 30° C.? See Table IX, Appendix.

10. What is the pressure of water vapor at the temperatures given in Ex. 9? See Table VIII, Appendix.

11. Under what conditions can you "see your breath"? Why does the condensed moisture disappear?

12. When you blow your breath into a cold, dry glass or lamp chimney, you form a deposit inside. What is the deposit? Its source? How cold must the condensing object be?

13. If the evaporation of water takes up heat (see § 54), what is the effect of condensing water vapor? Suppose that air containing moisture rises and expands until it is cooled below the dew point; what effect does the condensing of its water vapor have upon its temperature?

14. Get some accurate information regarding the size of hailstones.

15. If a dish containing a mixture of ice and salt is left outside on a very cold day, it gathers little, if any, frost; but when it is brought into a warm room, it condenses a great deal. Why?

16. Clouds are often formed on a headland near the sea or a large lake, which travel with the wind (horizontally) a short distance, and then disappear. Why are they formed? Why do they disappear?

17. There is a steep ascent of hills or mountains almost the entire distance around the coast of Australia. Would you expect the interior to be dry, or moist? What are the facts regarding Australia?

18. Does dew **fall?**

137. Air in Motion.—In § 111 we thought of air as one of the great natural **forces**; in § 128 we found that changes in the **density** of air are one of the causes of weather changes, because they produce air currents and winds. Let us imagine that there is, near the earth's surface, a layer of air all of the same density, and that some of it becomes *heated;* what will happen? We have already learned the answer in §§ 41 and 42: *ascending* air currents will be produced. If some of the layer of air were cooled, *descending* air currents would result. We have called such currents **convection** currents. We usually say that the heated air "rises"; what really happens (see also § 121) is that the surrounding, heavier air is **pulled,** by gravity, into the place occupied by the heated, lighter air, so that the heated air is **pushed up** in the form of a current.

The **density** of air becomes **less,** not only when air is heated, but also when it takes up **water vapor.** How can this be so? Because water vapor is **lighter,** volume for volume, i. e., has a lower density (see Table III, Appendix) than air. You know that a piece of lead will sink in water; yet you can float it if you tie a large cork to it. You increase the *weight,* of course, by adding the cork, but the *density* of the new body, made up of both lead and cork, is less than that of water, and the body floats. So air containing water vapor is lighter, volume for volume, than dry air.

How high will an ascending air column rise? Until it reaches a level at which its density is the same as that of the air surrounding it. Then it will be flattened out as horizontal currents (winds); in time these will descend again to the earth. Thus we get "circulation" in the atmosphere.

Since the pressure of the atmosphere depends upon the density of the air, a barometer (see § 15) placed in a region from which air is ascending will be low, because the region will be an "area of low pressure." The weather expert uses the barometer pressure in "forecasting" the weather; but we must remember that the barometer tells only the **pressure** of the atmosphere. If we wish to draw any conclusions regarding the **weather,** we need other facts besides the barometer reading. The **Weather Bureau** says the following:

Wind-Barometer Indications.— When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

138. The Winds.— Have you seen a large bonfire on a quiet evening? Its smoke and sparks rise almost vertically, and then move out horizontally before they come down (Fig. 113). If we could follow the invisible currents of air near the fire, we would find that they flow along the ground toward the fire, to take the place of the air which ascends. Thus there is a complete **circulation** of air, because some of it is heated by the fire. We do not feel the currents that ascend, nor those that descend; but we feel those which flow along the ground

There must also be horizontal currents at higher levels. The horizontal currents near the earth's surface are the **winds.** The cause of the winds is thus the **inequality** of atmospheric pressure. If the pressure becomes low at any given place, the surrounding, heavier air crowds in from all sides toward the "low" area. The lighter air is forced upward as an ascending current.

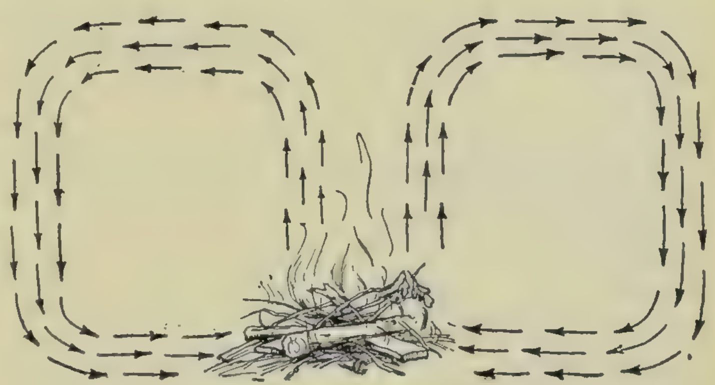


FIG. 113.
Air currents rise over a fire, or over the heated earth. When they reach a certain height, they flow out horizontally, and finally fall again to the earth's surface.

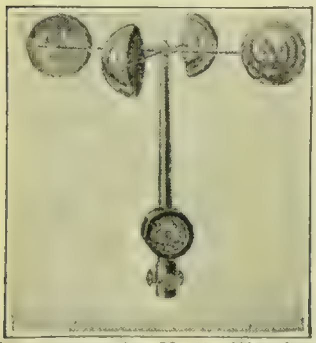
The **force** with which the wind will blow toward any given place depends upon the difference in atmospheric pressure between that place and the region about it. Thus, if the barometer pressure at one place (*A*) on a horizontal plain is 29.9 in., at another place (*B*), 29.8 in., and at a third place (*C*), 29.7 in., the velocity of the wind from *A* to *C* will be greater than that from *A* to *B*, or from *B* to *C*. We should expect this to be so, since we know that water will flow more rapidly down a steep slope than down a gentle one.

We can gather these facts together in one **law of the winds**:

The winds blow because of the force of gravity, and always from a region of high barometer pressure to one that is low. The velocity of the wind is greatest where the change of pressure is most abrupt.

The instrument by which we measure the velocity of the wind is the **anemometer** (ăn′ē-mŏm′ē-tẽr: from *anemos*, wind; and *meter*.

measure). It is a windmill (Fig. 114) with hollow, cup-shaped sails; the speed with which it revolves is registered on a dial in miles per hour. A **light** wind has a speed of less than 10 miles an hour; it can just move the leaves of trees. A **moderate to brisk** wind, 10 to 25 miles per hour, sways the branches of trees. A **high** wind, blowing at 25 to 40 miles an hour, sways the whole tree. In a **gale** the wind is from 40 to 65 miles an hour; it breaks branches and may uproot trees. In a **hurricane** or a **tornado** (see § 140) the velocity of the wind exceeds 75 miles an hour, and may reach 200 or more. See Appendix IV for the **Beaufort Wind Scale** used by the Weather Bureau.



Photograph by U. S. Weather Bureau.

FIG. 114.

As the vanes of the anemometer are turned by the wind they register the wind's velocity on the dial.

Winds may be **variable** or **regular.** On the land the unevenness of the surface and the different degrees of heating and cooling in different places cause **variable** winds; but the ocean provides a free, unbroken path; hence its winds often keep their direction for weeks and months at a time. Such regular, long-continued winds are the **prevailing westerlies** and **trade winds** of temperate latitudes and the **monsoons** of the Indian and West Pacific Oceans (see § 135).

Land breezes and **sea** or **lake breezes** are also regular, owing to the alternation of day and night. The land is heated more by day than the water is, and is cooled more at night (see § 98). As a result, ascending convection currents rise over the land during the day, and over the water at night. When the heated air current rises over the land, there is an inflow of cool air from the ocean—the sea breeze. Thus there is a sea breeze during the day. When night falls, and the ascending current is over the water, there is a flow of air from the land to the sea — the land breeze.

139. Great Storms: Cyclones.— The rotation of the earth has other effects besides the alternation of day and night. It has a very marked effect upon the winds. If the earth were not turning on its axis, winds would blow toward the area of low pressure as **directly** as possible, in straight lines, just as the spokes of a wheel come together at the hub. But the earth's rotation causes the air to flow toward the "low" by a **curved** route. Because the path of the wind is curved, the air at the center is set to **whirling.** A dust **whirlwind** is a circular air movement on a small scale; a **cyclone** is a great whirl that may be 1,000 miles in diameter and 5 miles high.

In the northern hemisphere the direction of this whirling mass of air is *opposite that of the hands of a clock.* If, in this hemisphere, you stand with your back to the wind, the center of low pressure will be towards the **left.** In the *southern* hemisphere the whirl is in the direction in which the hands of a clock move. In the center of the cyclone there is comparative calm. The whole area of low pressure moves in a definite direction. In the northern United States this direction is easterly; the cyclone begins in western Canada. The eastward movement is at the rate of about 30 miles an hour.

Cyclones must not be confounded with tornadoes (see § 140), which are smaller masses of very rapidly revolving air, and which do great damage. True cyclones bring the **cold waves** that sweep down upon us at more or less regular intervals, both in winter and summer, giving us fresh air and new vigor.

The curved path of the wind approaching a "low" area is the result of two motions: (1) the straight-line motion of the wind, by which it seeks the "low"; (2) the rotation of the earth from west to east. The path of a person on a revolving bridge (Fig. 115) can be made to illustrate the effect of these two motions. If the bridge is standing still, and you walk toward a street car on the opposite shore, your path will be a **straight line.** But suppose the bridge begins to turn, while you continue to walk toward the car. Your path on the bridge will change its direction at every point: it will be a **curve.**

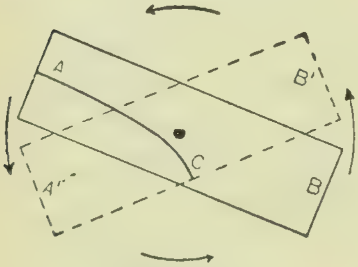


FIG. 115.

If you walk across a revolving bridge, and keep your direction toward some object on the opposite shore, your path will be curved, somewhat like the line *A C*.

140. Thunderstorms, Tornadoes, and Hurricanes.—

Thunderstorms are smaller storms in the great cyclones. They usually come after very warm weather. In certain portions of the tropics they come almost every afternoon for weeks at a time, and are accompanied by a great downpour of rain. The **lightning** that comes with them (Fig. 159) consists of great electric sparks that pass from cloud to cloud or between clouds and the earth. The electric charge upon the cloud is produced by the condensation of water vapor on a large scale.

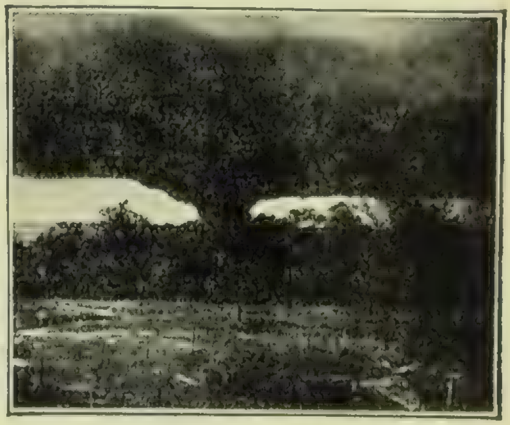


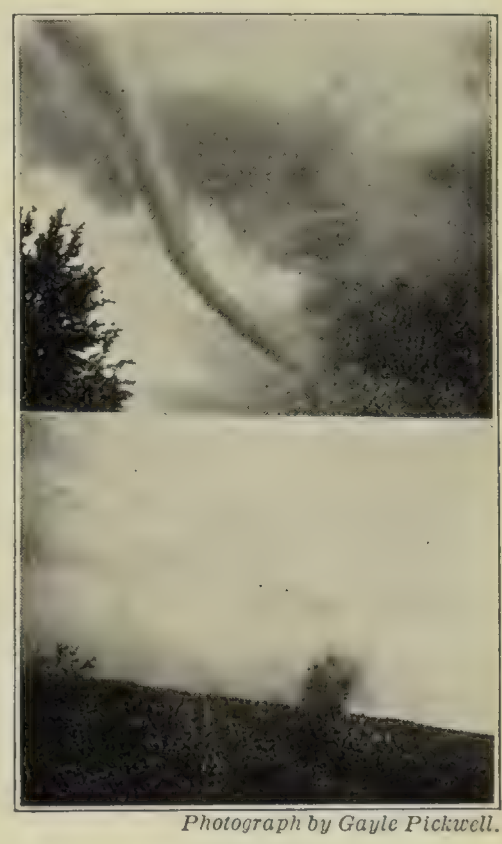
FIG. 116.

An ominous twister. Note how it differs from the slender one in Fig. 117.

Thunder is the vibration brought about in the air as the lightning flashes through it.

The cause of the great condensation of water vapor in a thunderstorm is an ascending column of warm air loaded with moisture (see § 137). When this has produced a large cloud (see § 132), rain falls, and cools the ascending column below the temperature of the warm, moist air that rises around it. The central, ascending column of air thus becomes a cool, descending one, which draws down into itself the wet, ascending currents, and precipitates their moisture in violent rains. A thunderstorm has a **center** of **high pressure** and **low** temperature; its circumference has a low pressure and a high temperature.

Tornadoes, or "twisters" (Figs. 116 and 117) are whirling masses of air 50 feet to half a mile in diameter. While the tornado is small, as compared with the great cyclonic storm, it is very violent and destructive. The air pressure at the center may be as low as 7 or 8 pounds to the square inch (what is the normal amount?), and toward this center the wind may blow as rapidly as 200 (some say 500) miles an hour (see the Law of the Winds, § 138). The density of air is small, but when moving with so great a velocity, its energy is enormous (see § 115). Tornadoes have been known



Photograph by Gayle Pickwell.

FIG. 117.

A tornado in action. Two films were needed to get it all in.

to carry away great boulders, cut houses in two, turn a locomotive over, and pluck the feathers from living chickens. So great is the force of the wind which hurls them that frail objects, such as twigs and straws, are driven into oak wood.

A tornado, as seen approaching, is a funnel-shaped cloud with the small end downward. The lower end dangles along the ground, touching it here and there. The whole storm moves northeasterly, in the northern hemisphere, at a rate of 25 to 40 miles an hour. It generally exhausts itself in an hour or two.

In the great deserts (where are they?) large **whirlwinds** carrying columns of sand continue for hours at a time. **Waterspouts** are tornadoes over bodies of water. At sea they precipitate **fresh** water. This fact shows that only a small amount of the water in the waterspout is actually forced up by atmospheric pressure ("sucked up"; see § 14) toward the low pressure center; most of the water is condensed from the air itself.

Hurricanes are violent storms that arise in the tropical Atlantic, north of South America. Similar storms in the Indian and Pacific Oceans are called **typhoons.** Both are whirling air masses, with a diameter of 300 miles or more, in which the violence of wind and rain becomes enormous. The "West India" hurricanes move northwest until they reach the southeastern coast of the United States (what states are these?); then they move in a northeasterly direction, and finally into the Atlantic. Sometimes they reach Western Europe. Once in a while hurricanes attack the Gulf States (what are they?), as on September 8, 1900, when Galveston and the country north of it suffered great damage. They usually come in the months of July to October, inclusive.

The damage to shipping and to life because of hurricanes is very great. It is not only the wind and rain that are so destructive, but also the great storm waves which are raised, and which sweep over all low-lying islands and coasts. Typhoons are still more extensive than hurricanes, because they arise and move in a greater ocean.

At the approach of a hurricane or typhoon, the sea and air are calm, and the barometer falls. Then the wind begins to blow, and clouds and rain come on. The velocity of the wind increases to that of the fiercest gale, or even to that of a tornado. If the center of the hurricane passes over a ship, the sailors notice a sudden change from black darkness and the most violent gale to a dead calm and a clear sky. But the storm is not over. The barometer will now be very low. The ship is in the "eye" of the storm, an area 10 to 20 miles in diameter. When this has passed, the wind will break forth again, as suddenly as it stopped, but it will come from the opposite direction. Then all the conditions that were noticed when the storm came on will be reversed as the ship passes out of the storm area.

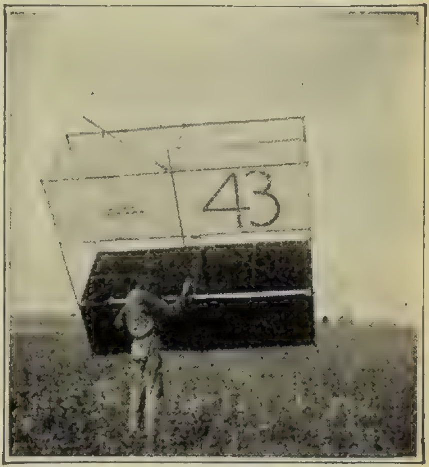
141. Weather Service of the United States.— Have you ever visited a "Weather Office"? You will find there delicate instruments for recording the direction and velocity of the wind and for measuring the rainfall or snowfall, the temperature, the atmospheric pressure, and the humidity. How is each of these obtained? Many of the stations are also equipped with sunshine recorders, barographs, thermographs, and other devices that make a **continuous, automatic record** of local weather conditions. The science of the weather is called **meteorology** (mē′tē-ŏr-ŏl′ō-gy̆). A **Weather Service,** or **Bureau,** is especially needed in a country like the United States, with its great range in latitude and longitude, and the corresponding variety in its weather conditions. Tell why. The Weather Bureau is a part of the Department of Agriculture. There are 200 regular observing stations in this country and the West Indies, besides many coöperating stations.

Each day at 8 A.M. and 8 P.M., 75th meridian time (see § 161), many trained observers gather the weather conditions of their stations. These are telegraphed immediately to Washington and to the "forecast centers" at Chicago, New Orleans, Denver, and San Francisco. When the results are put together on a weather map, they give the expert an instantaneous photograph of the weather of the whole country. By comparing the map with the ones preceding it the forecaster is able to trace the paths of **storm areas** from the time they appear, and to **foretell** the courses they will probably follow and the weather conditions that will accompany them. He can tell, in other words, not only what the weather **is,** but what it is likely **to be**: whether rain, snow, or frost is on the way, and whether it will be hot or cold in any given region.

Canada and Mexico have Weather Services similar to those of the United States, and daily reports are also received from the Azores, Iceland, the Faroe Islands, Great Britain, Germany, France, European Russia, China, Japan, the Philippines, Hawaii, and Alaska. It is plain that the weather expert has before him not only the conditions reported twice daily for the United States and the West Indies, but a view of what the weather is in practically the whole **northern hemisphere.** Not only this, but the Weather Bureau has also organized the taking of observations on upward of 192 vessels navigating the coast waters of the Middle and South Atlantic States, the Gulf of Mexico, and the Caribbean Sea. In this way the approach of hurricanes can be known (see § 140).

The observations are sent from the ships to shore stations by radio service, and then telegraphed to Washington, to be added to the weather charts of the day. A similar service is maintained on the Pacific coast.

Within two hours after the morning observations have been taken, the forecasts are telegraphed from the forecast centers to about 1600 principal distributing points, from which they are further distributed by telegraph, telephone, radiograph, radiophone, and mail. Great signs placed on trains often warn the farmer that a cold wave is on the way. Storm warnings are displayed at more than 300 points along the Atlantic, Pacific, and Gulf coasts, and the shores of the Great Lakes. So perfect is the service that shipping almost always has warning 12 to 24 hours in advance of a serious storm. The warnings regarding a single hurricane kept in port vessels and cargoes valued at $30,000,000. The warnings for a single cold wave resulted in saving over $3,500,000 worth of property. In the citrus fruit region of California fruit valued at $14,000,000 was saved through warnings of a cold wave. In the Mississippi River floods of 1912 it is estimated that the warnings of the Weather Bureau saved not only many lives, but also property valued at $16,800,000. The lumberman of Washington or Oregon is aided by the "fire weather" warnings of the Weather Bureau; the fruit grower in Utah learns when enough snow has fallen in the Wasatch Mountains to provide water for the next summer's irrigation; the cattle shipper learns when the weather will allow him to ship cattle to market; the farmer learns when to dig his potatoes; the sugar planter of Louisiana cuts his sugar cane, and the iceman his ice, all because of the information supplied by the Weather Bureau.



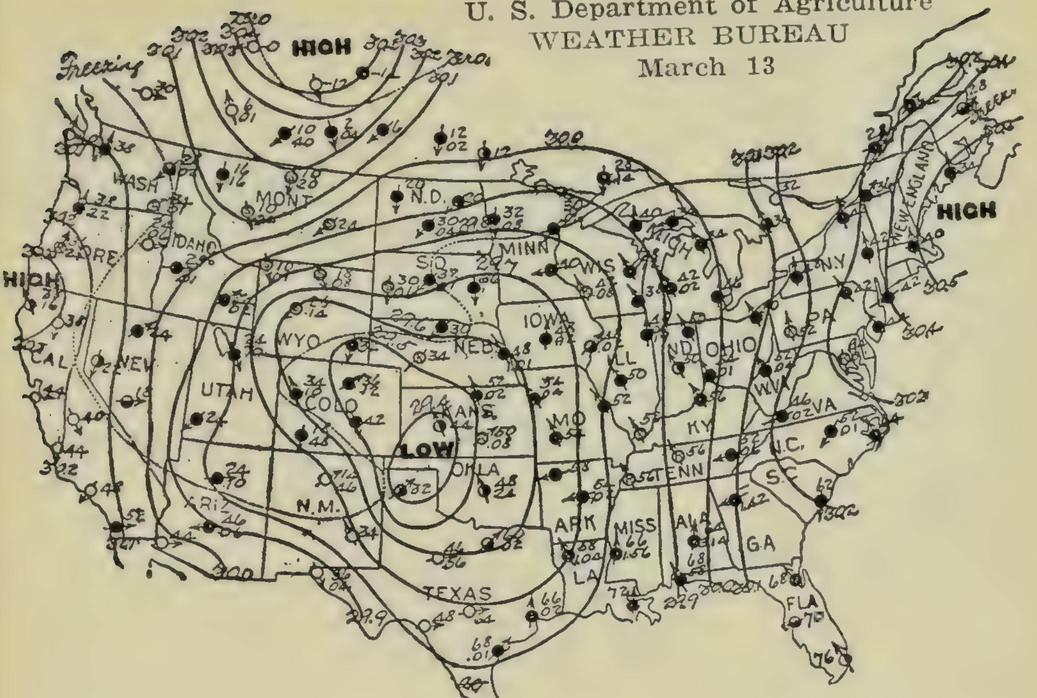
Photograph by U. S. Weather Bureau.

FIG. 118.
Launching a kite used in the study of the atmosphere.

In order to aid its own forecasts of weather conditions and to gain information for the use of aviators, the Bureau studies the upper air by means of **kites** (Fig. 118), **captive balloons,** and **pilot balloons.** Observations with balloons are made twice a day, and the results are telegraphed to district forecast centers. Here they are put into maps of different altitudes and issued in **aviation bulletins.** The bulletins show the air currents, probable future conditions of cloudiness, visibility, direction and speed of the wind, and often the best altitudes for flying. Man cannot yet control the weather, but he can take advantage of it when it is favorable, and make the discomfort and loss which it causes as small as possible.

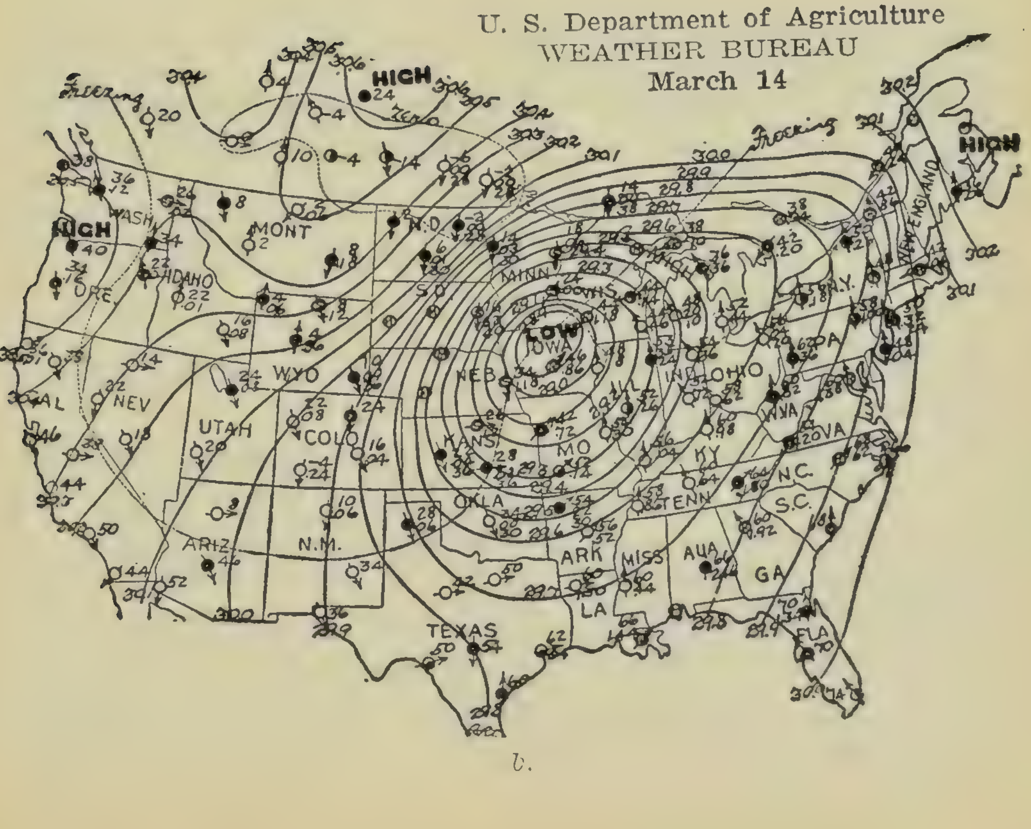
142. Weather Maps.— In § 141 we have learned how useful the Weather Service is to us. Let us now see how weather maps (Figs. 119, *a*, *b*, *c*) are made. Note that all stations having the same barometer height are joined by **solid** lines. These lines therefore show equal pressures, and are called **isobars,** from *isos*, "equal" and *barus*, "heavy." From the maps we can see that the isobars curve, in lines that are irregularly circular, about areas of low and of high pressure. The pressure increases from the centers of the "lows" to the centers of the "highs." The lows represent cyclonic storms, and the highs the sharp, bright weather that usually follows them.

Besides the isobars there are **dotted** lines that join places having the same **temperature**; these are called **isotherms.** On the maps only the isotherms for "Freezing" and "Zero" are shown. The maps show also the temperature of the weather stations, the direction of the wind, and the amount of rain or snow. Note carefully the progress of the "low" from March 13 to March 15, also the effect of the northwestern "high" upon the isotherm of freezing temperature.



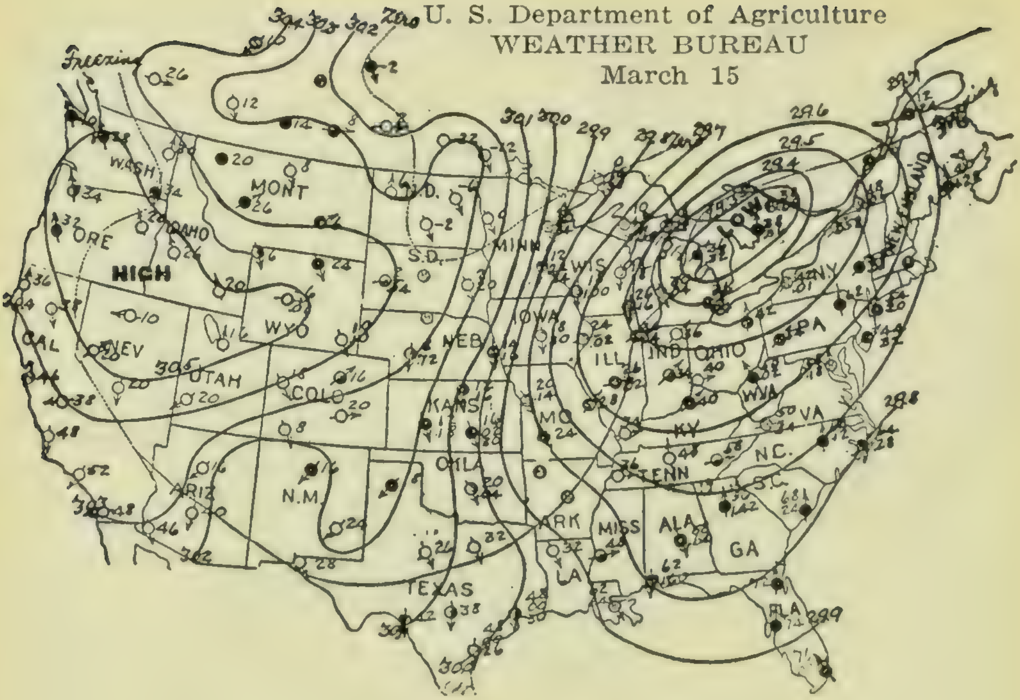
U. S. Department of Agriculture
WEATHER BUREAU
March 13

a.



U. S. Department of Agriculture
WEATHER BUREAU
March 14

b.



c.

FIG. 119.

Figs. 119, *a, b,* and *c,* are weather maps of three successive days.

EXPLANATORY NOTES.—Observations taken at 8 A.M., seventy-fifth meridian time. Air pressure reduced to sea level. Isobars (continuous lines) pass through points of equal air pressure. Isotherms (dotted lines) pass through points of equal temperature; drawn only for zero, freezing, 90° and 100°.

○ clear ; ◒ partly cloudy ; ● cloudy ; Ⓡ rain ; Ⓢ snow ; Ⓜ report missing.

Arrows fly with the wind. First figures, temperature; second, precipitation of .01 inch or more for past 24 hours; third figures (when entered) wind velocity.

143. Summary.— **Weather conditions** are due to changes in the air and water of the atmosphere.

The **causes** of weather are: (1) the atmosphere gains or loses heat; (2) the atmosphere takes up or loses water; (3) the density of the atmosphere is changed, so that heavier air pushes up lighter air. This change produces currents and winds.

About **70% of the heat** coming to the earth from the sun is temporarily absorbed, chiefly by the **lower atmosphere.**

Air **expands** as it rises, and is therefore cooled. As it descends, it is **compressed,** and therefore heated.

Evaporation of water is due to the energy of the water molecules.

When a given volume of air or space deposits moisture as rapidly as it takes up moisture, it is **saturated** with moisture.

The **humidity** of air is the weight of water in a given volume of air.

Relative humidity is the amount present as compared with what the air, or space, could hold if it were saturated.

The **dew point** is the temperature at which air is just saturated.

Frost is formed when the dew point is below 0° C. or 32° F. It is not frozen dew.

Clouds are fogs in the upper air. They are limited to regions in which water vapor can condense more rapidly than the condensed moisture can evaporate.

Clouds are distinguished, according to their form, as cumulus, cirrus, and stratus clouds. Nimbus clouds are other forms depositing rain or snow.

Rain occurs when water mist gathers in drops that reach the earth.

Snow is formed when the conditions that produce rain occur below 0° C. or 32° F. It is not frozen rain.

Hail usually has ice and snow in alternate layers.

Rainfall and snowfall are measured in a rain gauge.

The **mean annual rainfall** in the United States varies from a few inches in the deserts up to 100 inches in the state of Washington.

The **density** of a given volume of air becomes less, both when the air is heated, and when it takes up water vapor and becomes moist.

An **ascending** air column produces an area of low pressure.

Air circulation includes horizontal currents (winds) at higher levels as well as at the earth, and downward as well as upward currents.

Winds blow in **curved paths** toward regions of low pressure. Wind velocity is measured by the **anemometer.**

Regular winds include trade winds, prevailing westerlies, and land and sea breezes.

Cyclones are great whirlwinds in the air. They are usually not destructive, but bring "cold waves." In the northern hemisphere they revolve in a direction opposite that of the hands of a clock.

The **curved path** of the air in cyclones is due to: (1) the air's motion in a straight line; and (2) the rotation of the earth.

A **thunderstorm** has a center of descending air under high pressure, which draws into it ascending, moisture-laden air.

Tornadoes are small cyclones of great violence.

Waterspouts are tornadoes over bodies of water.

Hurricanes and **typhoons** are violent cyclones formed in the tropics.

Meteorology is the science of the weather.

The **Weather Service** of the United States collects data regarding the weather, and from them constructs daily weather maps. From these it forecasts hot and cold waves, floods, and storms. It also "charts the air" for the benefit of aviators.

144. Exercises.— 1. What is the difference between weather and climate?

2. Clouds often move in a direction exactly opposite that of the prevailing wind; what may be the explanation? Review §138.

3. What is a weather vane? What is its shape? Why? Why does a windmill often have a vane?

4. Fishermen on the sea coast often sail out to their fishing grounds at or before daybreak, and return in the afternoon. Do the land and sea breezes help, or hinder, them? Why?

5. Why does the wind often "pile up" the water in narrow bays?

6. Why does a falling barometer often show that a storm is coming?

7. Suppose that a cyclone is 5 miles high and has a diameter of 1000 miles; how many times its height is its diameter? If, to show these proportions, you make a circle out of boards 1 in. thick, how many inches in diameter must the circle be? How many feet?

8. If you were watching a barometer while a thunderstorm was passing, what change in its height would you observe as the center reached you? Would the same be true in the case of a tornado?

9. Would your house be more likely to collapse inward, or outward, if a tornado passed near it?

10. What direction do you think an air current has in the "eye" of a hurricane?

11. Find out the various flags used as weather signals.

12. In what ways, in addition to making weather forecasts, does the Government try to prevent loss of life and property at sea and on the lakes? What recent invention has been of great assistance?

13. At what hour, according to standard time at Washington, are the weather readings made at St. Louis? At Denver? At San Francisco? See § 161.

145. Projects.— 1. Construct a paper pinwheel, with and without a vane, and report the difference in its behavior.

2. Construct a simple rain gauge and snow gauge, and demonstrate its use.

3. Get the dew point of the air on a very dry day, a very moist day, and on a fair, average day, and report the results.

4. Take photographs of clouds of different forms, and mount and label them for a school collection.

5. Make a study of the different kinds of snow that fall during the winter, and give the weather conditions at the time.

6. Make a careful record of the snowfall during the winter.

7. Demonstrate by actual trial that compressing air raises its temperature. SUGGESTION: Compress air in a tire.

8. Demonstrate that air is cooled if allowed to expand. Hold a thermometer bulb in the air escaping from a tire.

9. Demonstrate the fact that fog is formed when air saturated with water vapor is suddenly cooled by expansion. SUGGESTION: Pour water from a large, small-mouth bottle held upside down. Note what happens in the air of the bottle at each spurt of water (which allows a sudden expansion of the air), and then what happens when an air bubble enters, and raises the air pressure. The result is seen best in a darkened room, with a beam of light passing through the air of the bottle.

10. Watch the behavior of a barometer, or a barograph, during a thunderstorm, and report it.

11. Report the behavior of a barometer for several successive days during the coming and going of a cold wave.

12. Take photographs of magnified snowflakes (out of doors) against a black background, and report the results.

13. Make a study of clouds and their forms for two weeks, and determine if they have any relation to the weather.

14. Make a record of the weather conditions in your neighborhood for 14 consecutive days.

15. Make a study of weather maps for 14 successive days, and give the story of the weather for those days through the country as a whole.

16. Prepare a chart for the class, showing the various weather signals in color.

17. Prepare for the class a large rainfall map of the United States.

18. Prepare a large chart showing the directions of the prevailing winds of the United States.

19. Prepare a chart showing the course of the great cyclonic storms of the United States and Canada.

20. Prepare a chart showing the course of tornadoes in this country.

146. References.— HARRINGTON: *About the Weather.* HOPKINS: *Elements of Physical Geography.* United States Weather Bureau Publications.

CHAPTER X

THE HEAVENLY BODIES

147. The Earth as a Heavenly Body.— Our earth appears to us as a more or less flat surface of land and water, and we speak of it in these terms in our common conversation. We like to think that the earth is a firm, solid floor on which we stand and on which we can depend. The truth is that we are too near the earth to see it correctly. We must imagine ourselves as being off in space and looking back at the earth; then we shall see it is a great, round ball, turning with dizzy speed from west to east and moving with still greater speed in its curved path, or **orbit,** around the sun.

Some people have the idea that Columbus was the first to believe that the earth is round; but the ancient Greeks knew this too. They had even worked out a method of calculating the earth's size. But the people of the Middle Ages did not know what the Greeks had done. So when Columbus, in the latter part of the 15th Century, said that our earth is a great ball, the people of his day could not understand him.

The Greeks not only knew that the earth is round, but also that it spins around, or **rotates.** As we know very well, the time of one rotation is a **day** (see, however, § 151). The imaginary line, or **axis,** about which the earth rotates, passes through the north and south poles.

How can we find the **diameter** of the earth? We could get the diameter of a croquet ball by drilling a hole through its center to the opposite side, and then measuring the distance. A better way is to put the ball between two blocks (Fig. 120) and to measure the distance between the blocks. Can we do this with the earth? Of course not; we must measure the distance **around** it: its **circumference**, and then **calculate** the diameter.

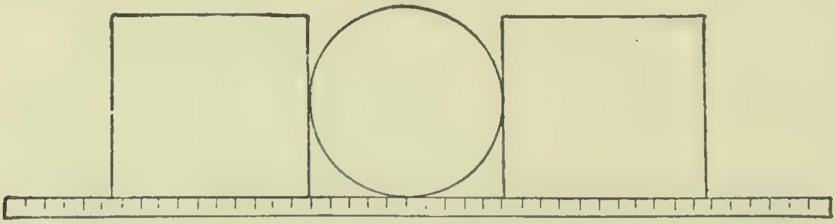


FIG. 120.
One way of measuring the diameter of a sphere.

With a tapeline measure the circumference of a circular plate or wheel; then measure the diameter, through the center. Divide the circumference by the diameter; what is the result? It should be about 3 1/7 (3.14159+). Then measure the circumference of a croquet ball, or a tennis ball, and calculate its diameter. Compare the result with that obtained by using the blocks.

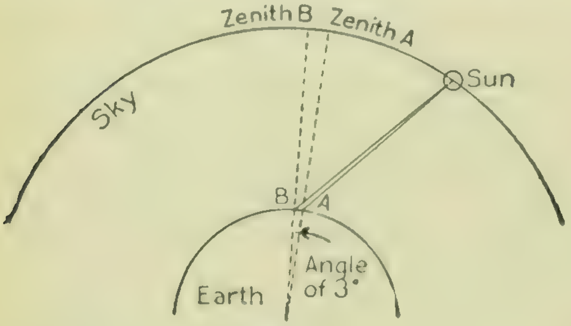


FIG. 121.
How we can calculate the circumference of the earth.

How can we measure the earth's circumference? No tapeline method will do, of course. First, we must remember that distances on a circle or sphere are measured in **degrees** as well as in units of length. There are 360 degrees (360°) in a circle, and each degree is divided into 60 minutes or 3600 (60×60) seconds. To get an idea of the earth's circumference, suppose you were to measure just how many degrees the sun is, at **noon** of a given day, from the point in the sky directly over your head (the **zenith**), and that some one else at a place 200 miles exactly north of you were to make the same measurement at noon of the same day. Would the number of degrees in this **zenith distance** of the sun be the same at the two places? No; anywhere in the north temperate zone the zenith distance would be greater for the place farther north. This is the same as saying that the sun will be farther above the horizon at the more southerly place. Tell why. Suppose the difference is 3°. Three degrees are $\frac{3}{360}$, or $\frac{1}{120}$, of the earth's circumference. The distance, in miles, between the two places is also $\frac{1}{120}$ of the earth's circumference. Hence, if 200 miles are $\frac{1}{120}$ of the circumference, the whole circumference is 120×200, or 24,000 miles.

Accurate measurements show that the circumference through the poles is considerably less than around the equator; there is a flattening at the poles. The mean circumference is 24,860 miles. The mean diameter at the equator is close to 7926 miles; through the poles, 7900 miles.

Any point on the earth turns through 360° in 24 hours, or 15° in 1 hour, or 1° in 4 minutes ($60 \div 15$). At the equator the rotation is most rapid: 24,902 miles in 24 hours, or at the rate of 1000 miles an hour, or 17 miles a minute. A degree of longitude is equal to 69.17 miles at the equator, but its width grows smaller and smaller as we go toward the poles. In the United States, in latitudes 40° to 45°, the rate of rotation is 12 to 13 miles a minute.

148. The Sky.— If you look along a straight line of telegraph poles, all of them seem, to the eye, at about the same place; yet your judgment tells you that they are not at one place, but one behind another. It is hard to tell which of a group of mountain peaks are near and which are farther away. All distant objects seem to be at about the same distance. So it is with the sky. The sky seems to be a hollow sphere, and the heavenly bodies all seem to move across its surface. Yet the truth is that the sky is a make-believe sphere, and that some of these bodies are enormously distant as compared with others. When we see a cloud, the moon, and a star near one another, they appear near together only because they are *in the same direction* from us, one beyond the other. Just in the same way the sun and moon at intervals of about four weeks (the time of "new moon") seem to be at the same place in the sky, although the sun is much farther away than the moon. How much? See §§ 152 and 153.

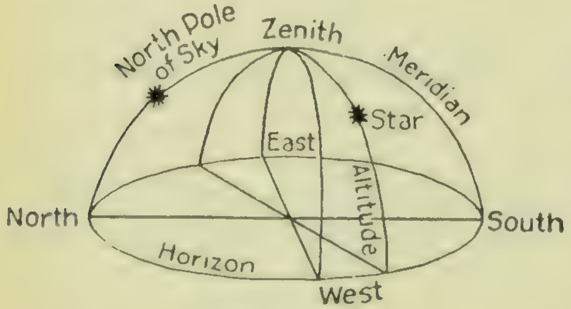


FIG. 122.

Imagine yourself at the center of the horizon, and locate the cardinal points of the horizon, the zenith, the north pole of the sky, and the east-west and north-south vertical circles. The latter is the meridian. A third vertical circle is given, to show zenith distance and altitude.

The circle in which the earth and sky seem to meet is the **horizon** (Fig. 122). We cannot see beyond it because the bulging surface of the earth is in the way. The horizon has its four **cardinal points**: north, east, south, and west. As we have already learned (see § 147), the point in the sky directly above us is the **zenith.** We find our zenith by determining the point at which a **plumbline,** if extended far enough, would pierce the sky.

We may imagine great semicircles passing upward from any point on the horizon, through the zenith, and then down to the opposite point on the horizon. Such circles are **vertical** to the horizon. The vertical circle that passes through the north and south points and the zenith is commonly called the **meridian.** Thus we say that the sun "crosses the meridian" at noon.

The distance across the sky, measured on a vertical circle, is 180°. The distance from horizon to zenith is 90°. We can locate a heavenly body in the sky by giving its **altitude,** in degrees, above a given point on the horizon. Thus, if a star is half the distance from horizon to zenith, we say its altitude is 45°; if two-thirds, 60°. We may also locate a body by giving its *distance* and its *direction* from the zenith. Both altitude and zenith distance must be measured on a vertical circle. If a star has an altitude of 50° above the horizon, what is its zenith distance? Why?

149. Some Star Groups.— If you look at the heavens on a bright night, you can hardly help noticing that some of the stars are arranged in groups which resemble, in a more or less fanciful manner, such objects as a kite, a sickle, a cross, a dipper, a chair, and so on. The ancient star-gazers of Chaldea, Arabia, Egypt, and Greece saw this too, but they saw a great deal more. To them the stories of heroes, of great monsters, and of important events were written in the stars; hence they gave these star groups, or **constellations,** appropriate names. Thus we have the constellation of the *Great Bear* (Ursa Major), of the *Bull* (Taurus), of *Hercules*, *Andromeda*, *Cassiopeia*, and *Orion*. Constellation comes from *stella*, the Latin word for star; the Greek word is *aster*. Can you name some English words derived from these? What is the origin of the word *disaster?*

Do you know any of the star groups? In the northern sky the *Big Dipper* is perhaps the most prominent con-

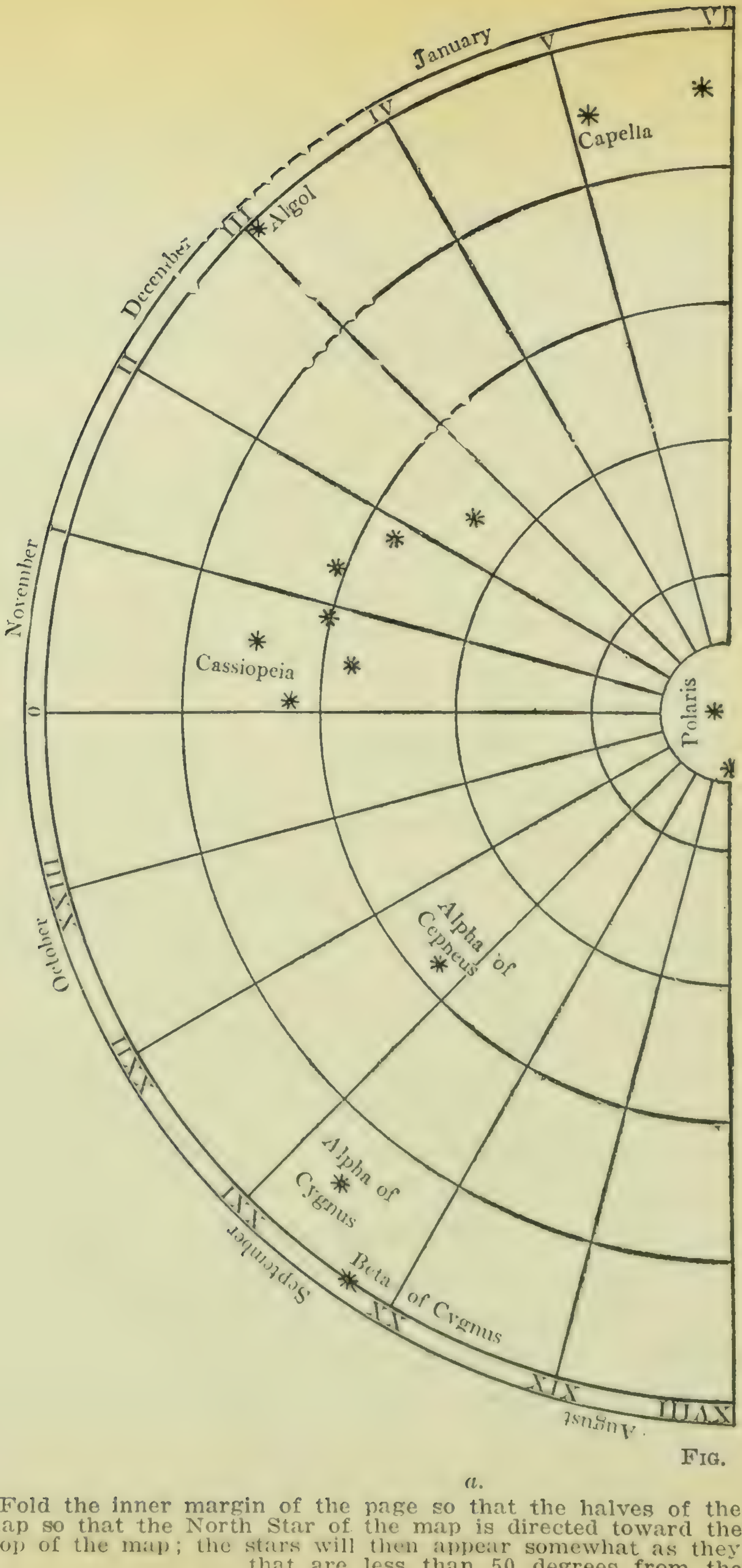
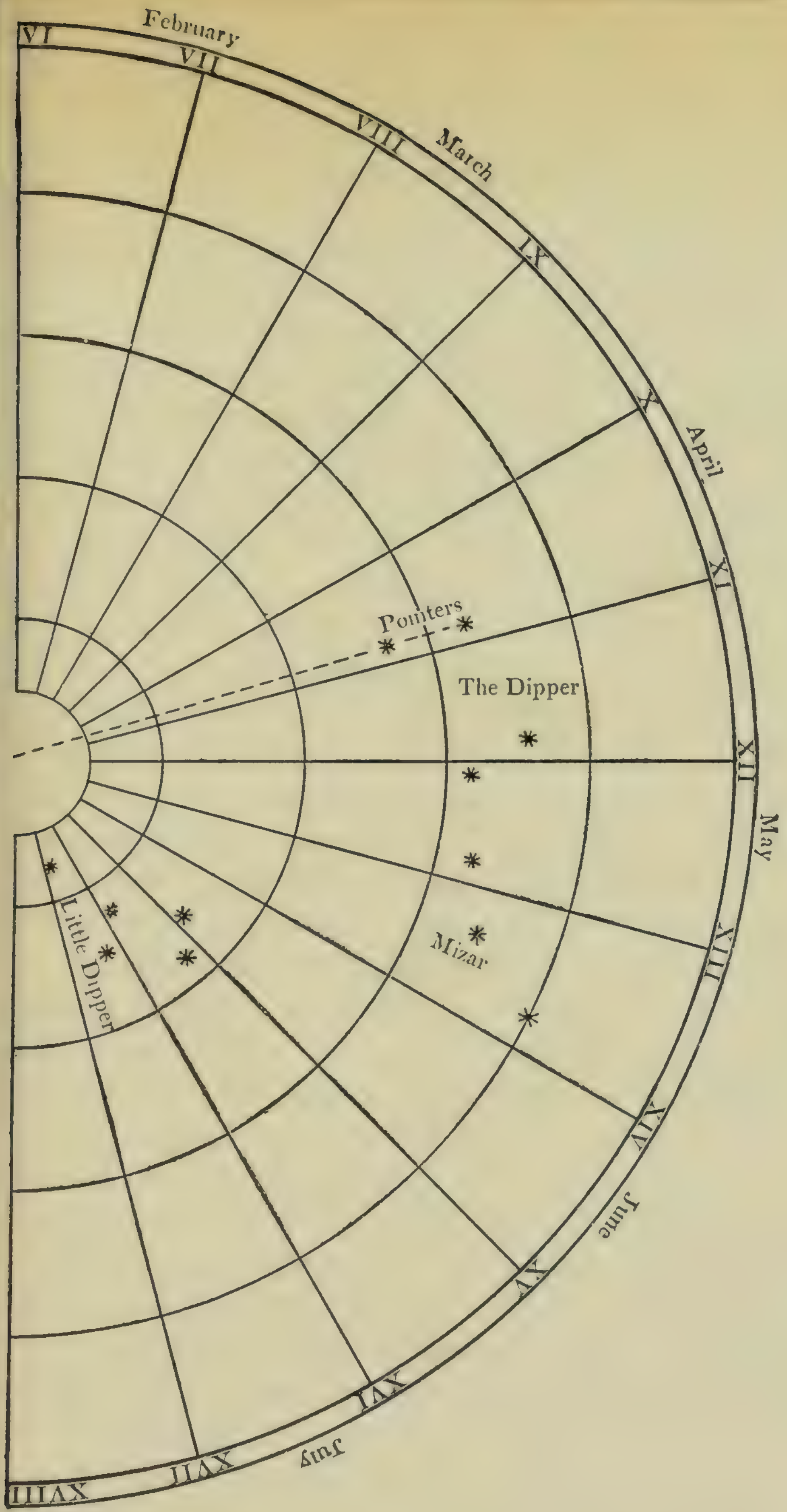


FIG.

a.

a and *b.*—Fold the inner margin of the page so that the halves of the
hold the map so that the North Star of the map is directed toward the
be at the top of the map; the stars will then appear somewhat as they
that are less than 50 degrees from the



123.

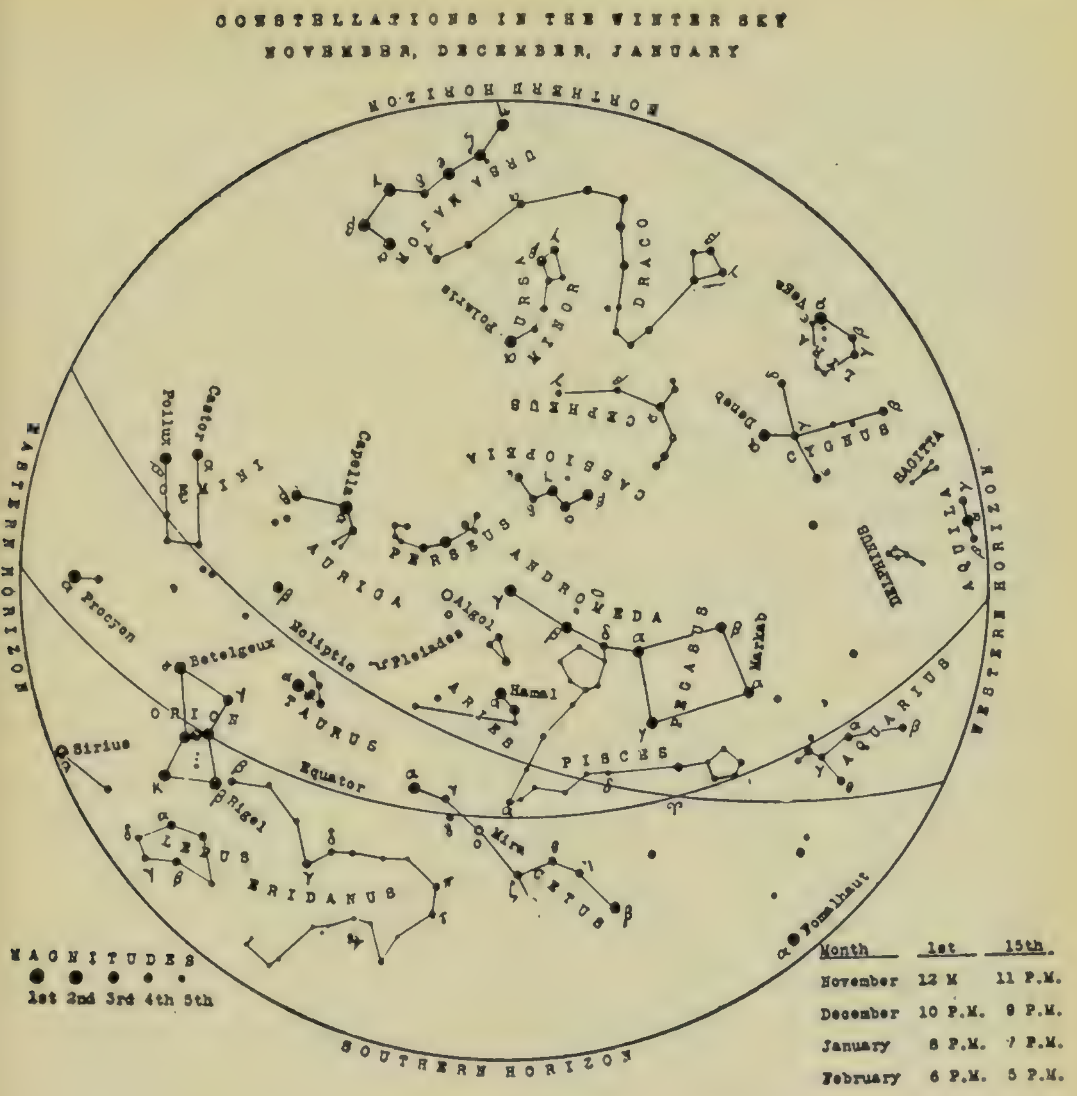
b.

map come together. Grasp the book with both hands, face north, and
North Star of the sky. Turn the map so that the present month shall
should be at about 8 P.M. The map shows some of the constellations
pole. (Suggested by Young's Astronomy.)

stellation. It consists of seven principal stars. Two bright stars, which make one side of the bowl of the dipper, point toward the North Star and are known as the "Pointers." The North Star is also called *Polaris*. The Big Dipper is a part of the larger group called the *Great Bear*. You will need more imagination to make out the shape of the Bear than to find the Dipper. Another group near the North Star is the *Little Dipper;* this is a part of the *Little Bear* (Ursa Minor). The North Star is at the end of the handle of the Little Dipper, or of the Little Bear's tail. See the star map in Fig. 123.

Another pretty, northern constellation is *Cassiopeia* (kăs′ĭ-ō-pē′ya). To find it, imagine a circle in the northern sky, with the North Star as its center; also that the circle passes through the Big Dipper. Look on the opposite side of the circle, and you will find Cassiopeia. It looks like a *chair*. To some it looks more like a *W*.

Perhaps our most beautiful group of constellations is the one we see in the east in the early evening during November and December (Fig. 124). First come the *Pleiades* (plē′yă-dēs), called the "Seven Sisters" by the Greeks. They cross the meridian at midnight about November 17th, and some ancient peoples used this event as the beginning of their year. The brilliant cluster of the Pleiades is followed by the bright, red star *Aldebaran* (ăl-dĕb′ă-răn) in the eye of *Taurus*, the Bull. Behind these and a little farther south is *Orion* (ō-rī′ŏn) with his belt of three bright stars and his sword of three fainter ones. There is a very bright, white star a little below and to the right of Orion's belt; this is *Rigel* (rē′gĕl). It belongs to the brightest class of stars, called



Month	1st	15th.
November	12 M	11 P.M.
December	10 P.M.	9 P.M.
January	8 P.M.	7 P.M.
February	6 P.M.	5 P.M.

FIG. 124.
Winter constellations. Yerkes Observatory.

stars of the *first magnitude*. Above Orion's belt is the bright, red star *Betelgeuze* (bē′tl-gūz); it is also of the first magnitude. After Orion comes the *Great Dog* (Canis Major), with the Dog Star, *Sirius* (sĭr′ĭ-ŭs). This is the brightest fixed star in the sky. Orion rises, almost exactly in the east, about 8 P.M. on November 22nd. It crosses the meridian at about 8 P.M. on February 4th.

At about 8 P.M., in late January and early February, a white, first-magnitude star is almost exactly at the zenith; this is *Capella*, in the constellation *Auriga* (ạ-rī′gă; see the Star Map, Fig. 123). It is believed to be giving off about 200 times as much light as our sun. In August, at about 8 P.M., the constellation *Lyra*, the Harp, is almost in our zenith. Its brightest star is *Vega*. Astronomers believe that Vega will some day be the Pole Star, that is to say, that the north pole of the sky will be near Vega, and not near Polaris. This change is due to the fact that the earth's axis, about which it rotates once a day, gradually shifts its position, so that the north pole of the sky makes a complete circle in about 26,000 years.

The *Galaxy*, or Milky Way (the Greek word for milk is *galax*), is a belt of light that extends across the heavens. When viewed through the telescope, the galaxy is found to consist almost entirely of separate stars (millions of them) each too small to be seen by the unaided eye.

150. Why Do Heavenly Bodies Rise and Set?— If you observe the sky, you find that the moon and the stars, like the sun, rise in the east and set in the west. Men once supposed that all these bodies revolve about the earth, but we have many proofs that the earth is rotating on its axis from west to east, and that it is this turning of the earth which brings us back each day to such a position that we can again see the objects of the sky. This is what we mean by the **rising** of the heavenly bodies. If you walk up a hill behind which there is a church, the church seems to *rise* above your horizon, although what is really happening is that you are moving toward the church, while the church is standing still. When you move away, the church seems to "set" behind the hill.

Are there any stars that do not rise and set, but are always above the horizon? If you live in the northern states and watch the position of the Big Dipper at a given hour, say at 8 P.M., every week or two during several months, you will find that it revolves about the north pole of the sky in a complete circle and is always **above** the horizon. The North Star itself is not exactly at the north pole of the sky, but revolves about it in a small circle. If a star is somewhat farther away from the sky's north pole than the last star in the handle of the Dipper is, it will be **above** the horizon part of the time and **below** part of the time; that is, it will rise and set.

If you were at the **equator,** all the stars would rise and set and their paths across the sky would all be perpendicular to the horizon. The North Star would be close to the horizon. To understand this we must remind ourselves again and again that the daily motions which the stars seem to have are due to the turning of the earth, and that the north pole of the earth always points to the north pole of the sky. The result is that all the stars seem to revolve around the north pole of the sky.

151. Fixed and Wandering Heavenly Bodies.— The stars like Polaris, Sirius, Aldebaran, and Vega, which keep their positions with respect to one another, so that they can always be found in a given constellation, are called **fixed** stars. While the stars in a constellation hold their places, the constellations themselves seem to move around the sky once each day owing to the actual rotation of the earth. But constellations have another apparent motion. If we watch one of them, such as the Pleiades, we shall see that it rises earlier and earlier in the evening, until at the end of six months, instead of rising in the east at sunset, it now rises and sets with the sun. Then, of course, we cannot see it at all, owing to the sun's bright light. After six months more the constellation again rises at sunset. What is the cause of this phenomenon?

Hitherto we have spoken of a day as the time taken by the earth for one rotation. This is not strictly true. Our day (**solar** day) is really the time that elapses between one noon and the next, that is, between one passage of the sun across the meridian and its next passage. This time is divided into 24 hours. The time occupied by the earth in making one rotation is a little less than 24 hours; it is 23 hours, 56 minutes, and 4.09 seconds. The reason why a day and the time of one rotation are not exactly the same is that the *sun seems to move eastward among the stars.* The earth also turns from west to east. When the earth has turned far enough to bring the sun to the meridian, the sun is not there; the earth must continue turning nearly 4 minutes longer to bring the sun into the exact position of the day before. If we

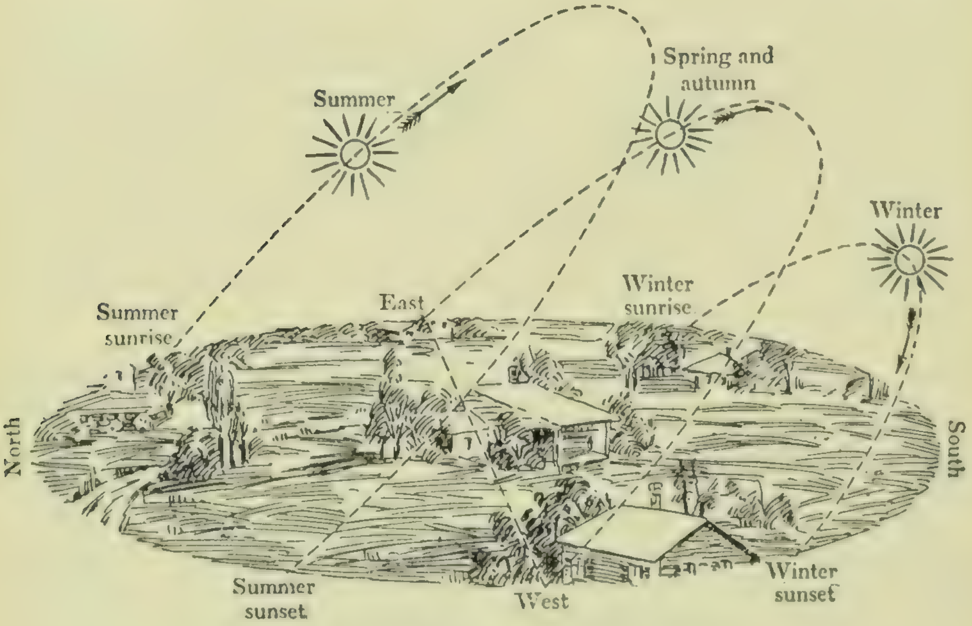


FIG. 125.

The daily path of the sun across the sky in the four seasons of the year. When is the sun above the horizon for the longest time? For the shortest? When are day and night equal? (Suggested by Todd's Astronomy.)

think of the stars and constellations as *fixed* in the sky, the sun must be a *wanderer*. First it is in one constellation and then in another farther east, until it has gone entirely around the heavens in a great circle. If you will study an almanac, you will find the list of "Signs of the Zodiac." Zodiac means "animal circle"; it is made up of the twelve constellations through which the sun seems to move. The ancients used them to tell seasons.

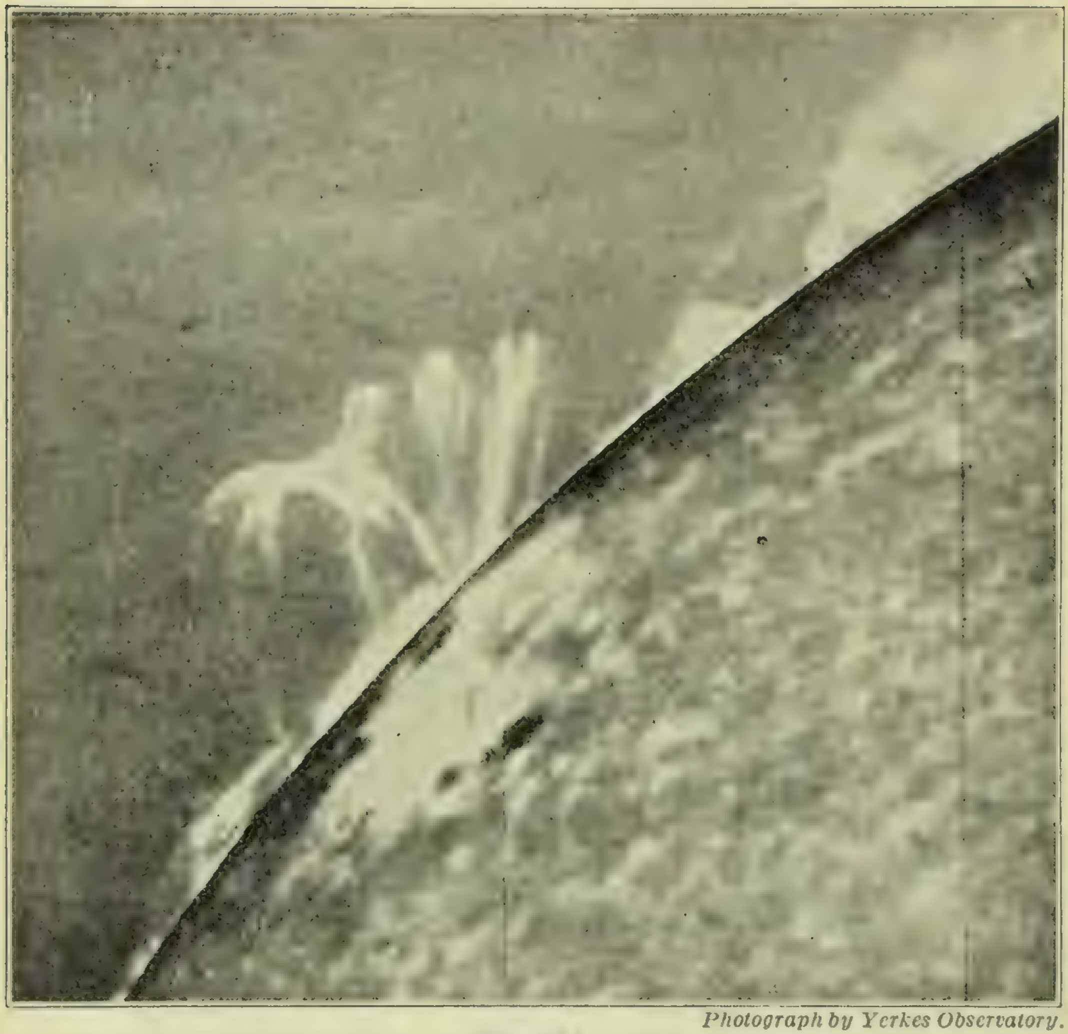
Why does the sun seem to make the circuit of the sky once each year? We must use our imagination to understand the answer. If we think of ourselves as off in space, watching the motions of the earth, we can see that what seems to be a movement of the sun among the constellations is really due to the revolution of the earth around the sun. When the sun seems to be in a certain constellation, the fact is that the constellation and the earth are on opposite sides of the sun. If we really wish to know what our earth is doing, we must accustom ourselves to **two apparent motions** in the sky, both of them due to the motions of the earth itself:

(1) The change from sunrise to sunset and from sunset to sunrise, caused by the **daily** rotation of the earth. Of course "star rise" and "star set" are due to the same cause.

(2) The **yearly** changes in the sky, caused by the fact that we are being swept around the sun and back to the starting place, once every twelve months.

You have all had the strange experience of imagining that the train on which you were riding was standing still, while trees, houses, and people were rushing by. This is the kind of experience we have all our lives, if we do not compel ourselves to think clearly about what is really happening.

The **moon** is also a wanderer in the sky, making the circuit from new moon to new moon in a *lunar month* of about 29 days. Besides the sun and moon there are other heavenly bodies that do not remain in fixed constellations;



Photograph by Yerkes Observatory.

FIG. 126.
Eruptive prominence and disk of the sun.

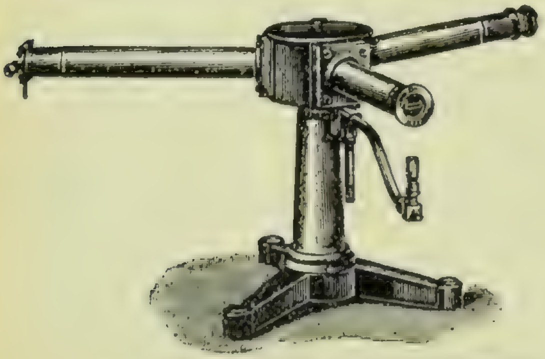
among them are the **planets,** or wandering stars. The planets seem to move irregularly among the stars because they really revolve around the sun, just as our earth does. As is the case with the sun, when they seem to be in a certain constellation, they are really between the earth and that constellation.

152. The Sun.— The sun is a **star** having a diameter of about 864,000 miles, or about 109 times the diameter of the earth. Its volume is over a million times that of the earth (109×109×109). In the sky it seems to have about the same diameter as the full moon, but this is due to the fact that it is much farther away than the moon. Its diameter is really 400 times that of the moon (864,000÷2160). The sun rotates upon its axis.

The **heat and light** given off by the sun are enormous, but our earth is so small that it can catch only a tiny part of them: perhaps 1 part out of 2,000,000,000. Still this small part is what makes the earth a fit place for living creatures, instead of a dead world. The surface temperature of the sun has been calculated to be about 6000° C. What is this on the Fahrenheit scale? See § 48. If the sun could be covered with a layer of ice 60 feet thick, the amount of heat given off by the sun is great enough to melt all this ice in one minute. Every square foot of the surface is giving off energy enough to do about 8000 horse-powers of work. There are several theories as to the cause of the sun's heat. One thing is certain: the sun is not a **burning** body, as a piece of white-hot coal is.

If we use a smoked glass, we can look at the sun's surface. Often there are irregular spots darker than the rest of the surface; these are **sunspots.** They move across the sun's face like great storms from a few hundred to perhaps 50,000 miles in diameter. Think of a great star across the surface of which enormous masses of highly heated matter in a gaseous or semi-liquid state move with incredible speed, while other masses shoot up to the height of hundreds of thousands of miles (Fig. 126), and you have some idea of what the sun is like.

By means of the **spectroscope** (Fig. 127), men have studied the composition of the sun, and have found out that its atmosphere contains many of the elements of which our own earth is made up (see Table X, Appendix). There are oxygen, hydrogen, and carbon, iron, nickel, copper, and silver, calcium, sodium, potassium, zinc, tin, and lead, as well as many others. The gas **helium,** which has become of importance, in the last few years, for the filling of airships (see §120), was discovered in the sun's atmosphere several years before it was found in the earth. Helium is, next to hydrogen, the lightest gas known, but unlike hydrogen it does not burn (see § 101).



Courtesy of the Central Scientific Co.
FIG. 127.
A spectroscope.

Around this enormous, active star that we call our sun the earth and planets and their moons revolve, and from it they derive heat and light according to their size and the distance at which they are placed. We have thought of the orbit of the earth as a *circle,* but it is really an **ellipse** (see Fig. 128); the same is true of the orbits of the other planets. On January 2 the earth is about 91,500,000 miles from the sun, on July 3, about 94,500,000; the average is 92,900,000. The speed of the earth in its orbit is about 1000 miles a minute, or 18 miles a second. This is perhaps 40 times the speed of a bullet as it leaves the muzzle of an army rifle.

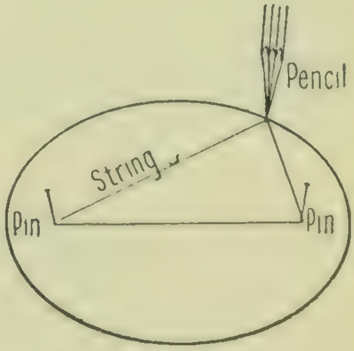
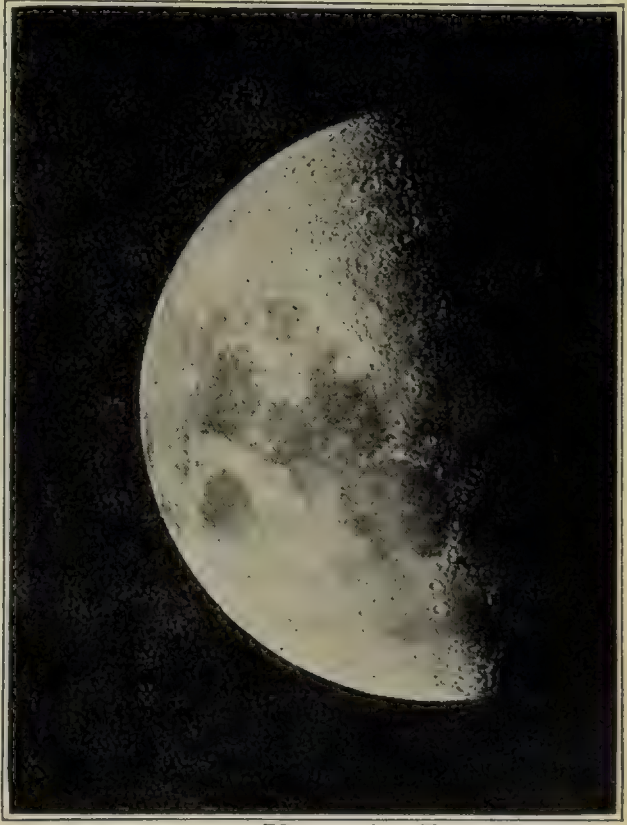


FIG. 128.
How to draw an ellipse.

We may repeat these figures, but they mean very little to us. We can get a better idea of our distance from the sun by remembering that the sun's **light,** which travels at the rate of about 186,000 miles (300,000 kilometers) a second, requires over 8 minutes (499 seconds) to reach us. A **train** travelling a mile a minute would require about 178 years to reach the sun; even a swift **airplane,** speeding continuously at the rate of 100 miles an hour, would need about 100 years. Yet such are the distances of space that the earth's distance from the sun is very small as compared with its distance from the stars. The light of the nearest fixed star needs about **4 years** to reach us, and the light of the North Star, that comes to our eyes tonight, left the star perhaps 47 years ago. The very **units** of earthly distances are too small for such spaces. Instead of our mile of 5280 feet or our kilometer (3281 feet) astronomers use the **light-year** as a unit: the distance which light travels in a year. This is about 63,000 times the distance of the earth from the sun, or 63,000 × 93,000,000 miles.

153. The Moon.— After we have travelled, in imagination, the enormous distances to the sun and the far-away stars, the moon seems very close to us. It is indeed our nearest neighbor in the heavens, and its average distance, 240,000 miles, is comparatively small. How does this compare with the earth's circumference? The moon is much smaller than our earth; its diameter is 2160 miles, and its volume about $\frac{1}{49}$ that of the earth. As we



Photograph by Yerkes Observatory.

Fig. 129.

The moon at 7 days.

examine the surface of the moon with a telescope (Fig. 129), we find both smooth plains and rugged mountains. There are many hollows which look like the bowl-shaped tops of volcanoes and are therefore called **craters.** The naked eye sees some of these irregularities in the fanciful form of the "man in the moon."

The most striking thing about the moon is its changing shapes, or **phases.** Some evening, just after sunset, we see a slender *crescent* in the west, the tips of the crescent being turned *east,* away from the sun. This is really a day or two after new moon, because the new moon's position in the sky is too near that of the sun for us to see the moon at all. The next evening the crescent is thicker and farther away from the sun. When the moon is about a week old, it is at "half moon" and sets about 6 hours after the sun. The period from new moon to half moon is called the *first quarter.* From new moon to full moon the moon is said to be "waxing," or growing; why? The full moon rises at sunset and sets at sunrise; explain this. From half moon to full moon is the *second quarter.* After full moon the moon "wanes." In the *third quarter* it shrinks to half moon, and in the *fourth quarter* it becomes a crescent once more (the "old moon") with its "horns" pointing *west,* again away from the sun. At new moon the moon rises and sets with the sun; but since it rises about 50 minutes later, on the average, each day than the day before, it soon appears again as a crescent just after sunset.

The cause of the moon's phases is, of course, the fact that the moon shines by the reflected light of the sun, and that only half of its surface is lighted at a time. Why is this true? We see only that part of the lighted surface which is turned toward us. At new moon we see none of it; the crescent is a thin edge of it. At half moon we see half of the lighted surface; at full moon all of it. When we see the "old moon in the new moon's arms," we see the "old moon" by **earth shine,** that is, by sunlight that is first reflected by the earth to the moon and then back from the moon to us.

154. The Moon and the Earth.— The moon revolves about the earth in an almost circular orbit, and the two together revolve about the sun. The moon rotates on its axis in such a way that the same face is always turned toward the earth; we never see "the other side of the moon." As we have already learned (see § 151), the time from one new moon to the next is a "moon," or *lunar month;* it is about 29 days, and was formerly used in reckoning time. The American Indian spoke of an event as happening so many "moons" ago. Moonlight sometimes seems fairly bright; but the fact is that the earth receives more heat and light from the sun in a quarter of a minute than it receives from the moon in a year.

In some important respects the moon is very different from the earth: it has no atmosphere and no water, for example. The reason given for the absence of an atmosphere is that the moon is not of sufficient size. The moon's mass: about $\frac{1}{80}$ that of the earth's, cannot exert enough force (gravitation) to hold a gaseous mantle to itself.

Then, too, the moon's rate of rotation is so slow that day and night are each about *two weeks* long. As a result of this fact, and because it has neither atmosphere nor water, the moon must have a climate of great extremes of heat and cold. Do you think it likely that such a world is able to support life?

One important effect of the moon upon the earth is that there are **tides** upon our oceans. The attraction of the moon (gravitation) produces a slight **bulging** of the earth's water level in the direction of the moon. In the deep ocean this bulging is probably not more than a foot, but when the bulge reaches a coast it causes the water to rise several feet. In funnel-shaped bays, like the Bay of Fundy (where is this?), the water may rise 50 feet. The sun also causes a tide, but a much smaller one, because of the greater distance of the sun from the earth. When the sun, moon, and earth are nearly in a straight line, the combined attractions of the sun and moon produce the highest tides, called **spring** tides. Would this be true at new moon? At full moon? What is the **flow** of the tide; the **ebb** of the tide?

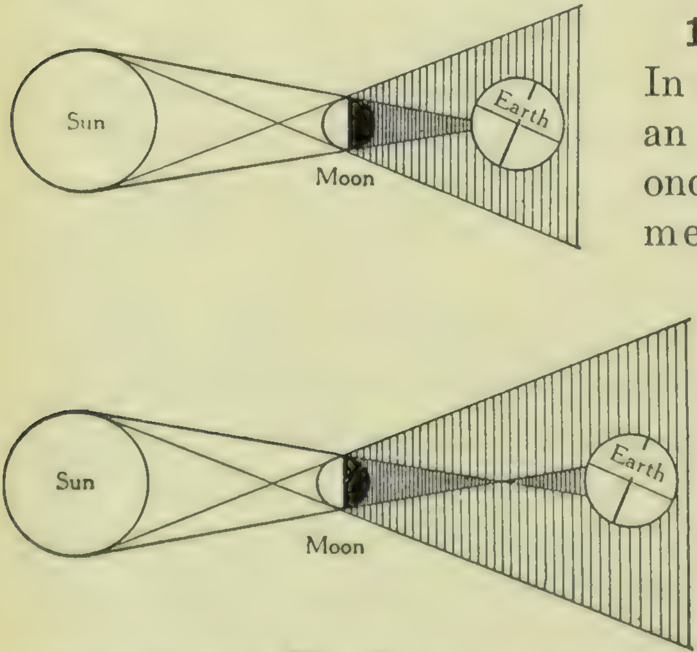
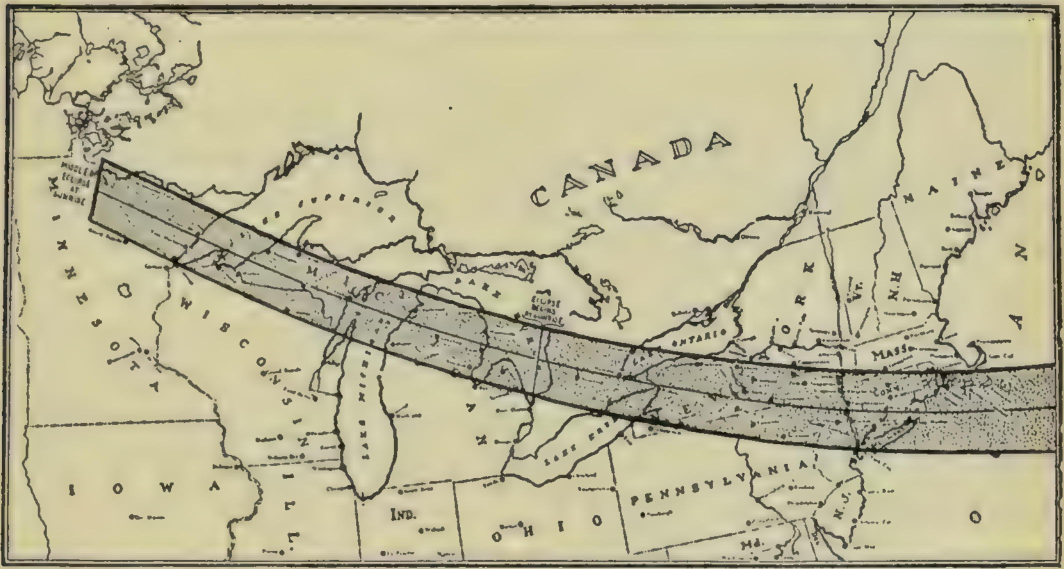


FIG. 130.
Positions of the sun, moon, and earth during an eclipse of the sun. All places within the umbra have a total eclipse. In the lower figure the umbra does not quite reach the earth, hence, to an observer directly behind the moon, the moon appears to be a great round disk, not quite large enough to cover the sun.

155. An Eclipse. — In § 1 we learned that an eclipse of the sun once caused terror to men, but it is now known to be a perfectly natural phenomenon, caused by the moon's coming exactly between the sun and the earth. This can occur only at the time of new moon. Another way of saying this is that the moon's **shadow,** that portion of space from which the moon cuts off the sun's light, sometimes reaches the earth. Similarly the moon is eclipsed when it passes into the earth's shadow.

When a source of light is very small: almost a **point,** the shadow cast by an opaque object placed in the light is very **distinct,** and just as dark in one part as in another; but when the light-giving body is large, so that there are *many points* giving off light, the shadow will have a darker portion, the **umbra,** from which **all** light is cut off, and a lighter portion, the **penumbra,** from which only a **part** of the light is cut off. This is the case with the sun's light.



Courtesy of the Monthly Evening Sky Map.

FIG. 131.
Path of the total eclipse of the sun, January 24, 1925.

Fig. 130 shows the positions of the sun, moon, and earth during an eclipse of the sun. Because of the small size of the moon and its distance from the earth, the umbra of the moon's shadow is never more than 168 miles in diameter as it sweeps over the earth. At such a time all places within the umbra have a total eclipse of the sun. This lasts only a short time, usually only one or two minutes (Fig. 131).

Since the earth is much larger than the moon, the umbra of its shadow is also larger, and extends far beyond the moon. The moon may require two hours to pass through it.

The motions of the moon and the earth are so well known to astronomers that the time of total eclipses of the sun can be calculated for many years ahead, and the places at which such eclipses are to be visible can also be foretold with great accuracy. By the same methods the times of total eclipses of the sun and the places where they were visible in ancient Greece, Egypt, Babylonia, or Assyria, can be calculated. If an ancient writer speaks of a total eclipse of the sun, that occurred about a certain time, and gives the place at which it took place, astronomers can find the date. This is one way in which the dates of ancient history are fixed.

156. The Planets.— We have already learned that planets are wandering stars (see § 151) and that their apparent, irregular movements among the stars are due to their revolution around the sun. In the order of their distance from the sun (Fig. 132) the planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus (yū′rǎ-nus), and Neptune. Two of these (see Table): Mercury and Venus, are nearer the sun than the earth is, while the remaining five are farther away. Mercury, Venus, and Mars are smaller than the earth, the others much larger. Jupiter, the largest, has a diameter nearly 11 times that of the earth. All the planets together contain only about $\frac{1}{700}$ as much matter as the sun. Uranus and Neptune cannot be seen without a telescope.

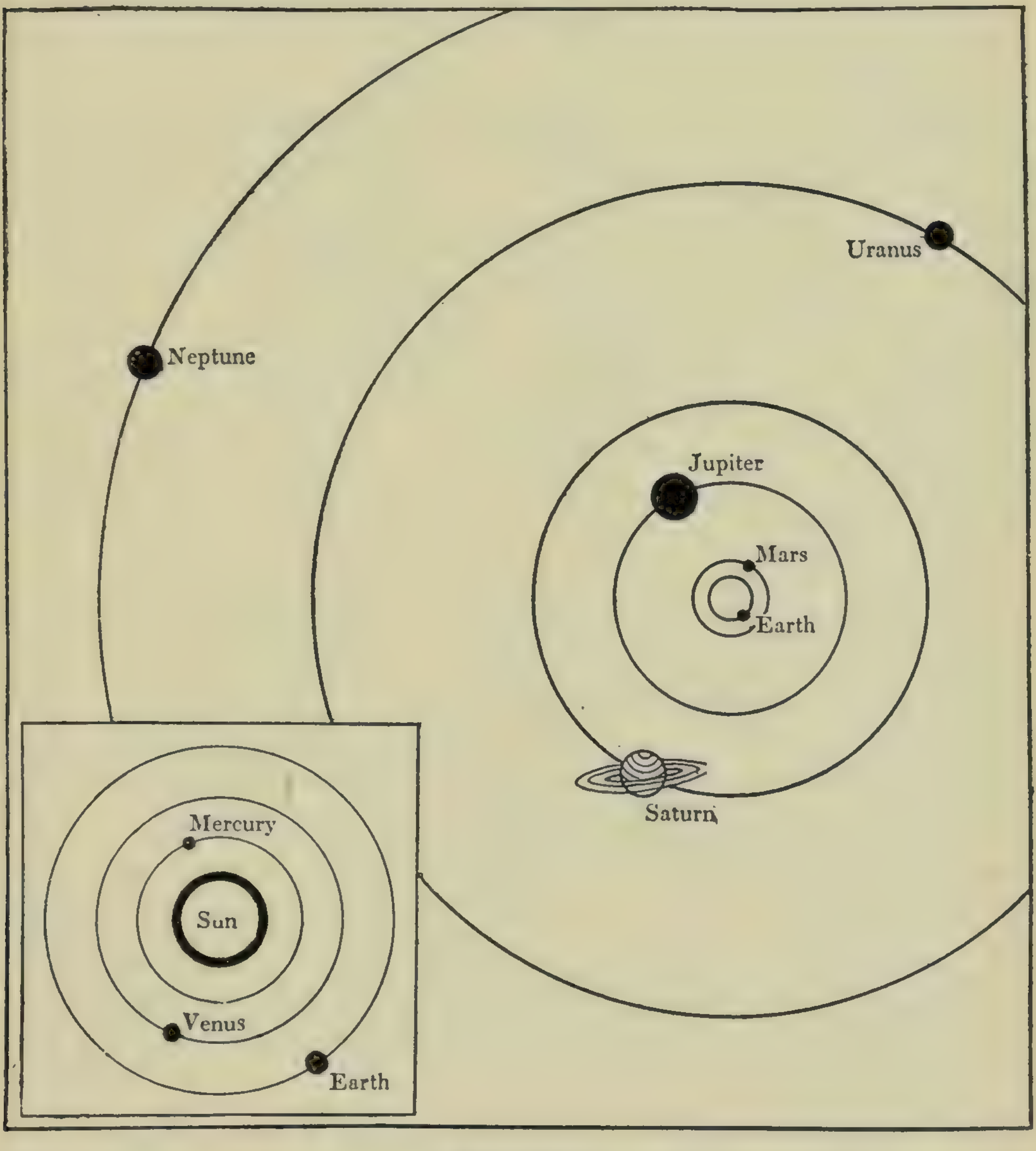


FIG. 132.

The planets and their orbits. The distance of Neptune from the sun is nearly 2,800,000,000 miles.

All of the planets are in the same belt of constellations· the Zodiac, in which we see the sun and moon.

THE PLANETS, SUN, AND MOON

Name	Diameter in Miles	Distance from Sun, in Miles	Time of One Revolution around the Sun
Mercury	3,009	36,000,000	3 months
Venus	7,701	67,200,000	7.5 months
Earth	7,918	92,900,000	12 months
Mars	4,339	141,500,000	22 months
Jupiter	88,392	483,300,000	12 years
Saturn	74,163	886,000,000	29.5 years
Uranus	30,193	1,781,900,000	84 years
Neptune	34,823	2,791,600,000	165 years
Sun	864,392	....	....
Moon	2,160	92,900,000	12 months

The planet **Mercury** is always seen in that part of the sky near the sun. **Venus** is also in the same part of the sky, but it may be as much as 47° from the sun. When Venus rises before the sun, it is *morning star;* when it sets after the sun, it is *evening star.* When Venus is almost between the earth and the sun, it has the shape of a *crescent*, like a new moon; when it is on the other side of its orbit, with the sun almost between it and the earth, it is round, like a full moon. Does this indicate that Venus shines by its own light, or by the reflected light of the sun? When it is most brilliant, Venus causes distinct shadows.

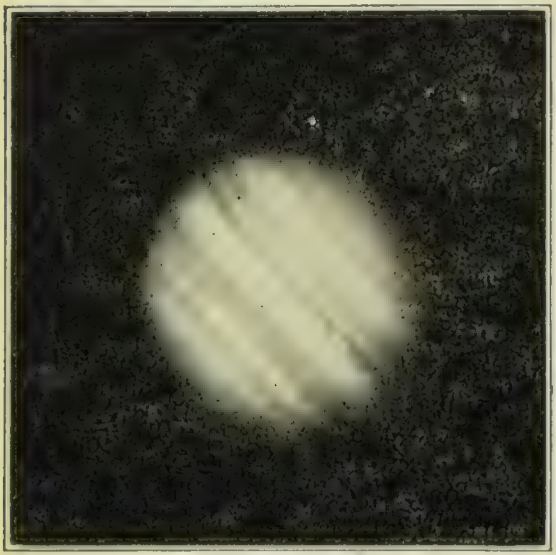
Venus is almost as large as the earth, and it has an atmosphere, as the earth has. Its climate is probably considerably warmer than that of the earth.

157. The Superior Planets.— Mercury and Venus may be called "inferior" planets, because they are nearer the sun than the earth is. The remainder of the planets, beginning with Mars, may then be called "superior" planets. The inferior planets may come between the earth and the sun, but the superior cannot. They are nearest the earth when the earth is between them and the sun (see Fig. 132).

Mars is known as the "red" planet from the color of the light which it reflects to us. It has an atmosphere, as Venus and the earth have; but while the atmosphere of Venus is "cloudy," so that astronomers cannot be sure what the surface of the planet is like, the atmosphere of Mars is thin, and apparently dry, and its surface can be seen and studied. As a result of this study we know that Mars rotates on its axis in almost the same time that the earth does: in 24 hours and 37 minutes. Its year is almost twice as long as ours, and its seasons likewise.

When there is winter at one of the poles of Mars, a white "polar cap" appears. It seems to us that this must be snow or ice. When spring comes to the pole, the cap disappears. Does the snow melt to form streams of water for a "growing season" of living things, or does it evaporate almost immediately into the planet's atmosphere? We do not know. But there seems to be water on Mars.

Jupiter (Fig. 133) is the greatest of the planets, with a diameter almost 11 times and a volume about 1200 times that of the earth. It is more brilliant than any of the fixed stars. The diameter of Jupiter is about 84,000 miles; what must its circumference be? About 260,000 miles, must it not? The planet rotates once in about 10 hours. How rapidly must a spot at the planet's equator be moving? About 26,000 miles an hour, or about 26 times as fast as an object at the earth's equator (see § 147). As a consequence the **centrifugal force** (see § 113) of the matter at the planet's equator is enormous, and produces a great bulging, with a corresponding flattening at the poles. The planet shows a distinctly *spheroidal* form.



Photograph by Yerkes Observatory.

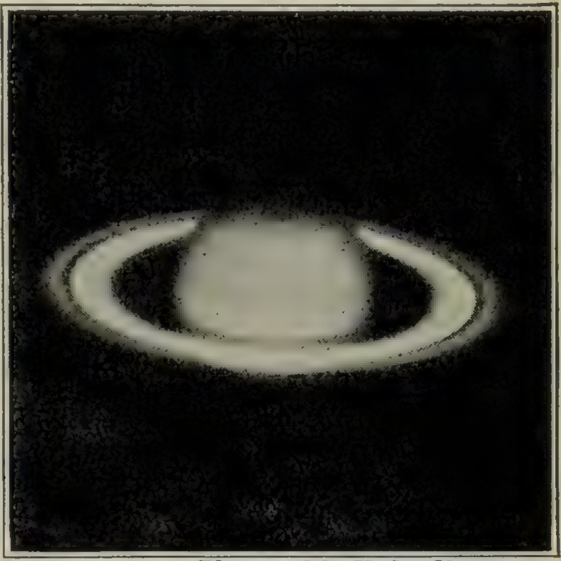
FIG. 133.

Jupiter. Note the bands on its surface, also the bulging toward its equator.

The earth has but one moon; Jupiter has at least 9. Galileo, with the first telescope used by man to study the sky, discovered 4 of them. The largest ones can be seen with opera glasses when in a favorable position.

Saturn, the planet with the rings (Fig. 134, *a*), is a little smaller than Jupiter, and like it has a day about 10 hours long. It is a most beautiful object when seen through the telescope. The rings revolve about the planet in the same plane as its equator. They seem to be solid, but are really made up of swarms of small particles. When the planet is in such a position that we look at the *edge* of the rings, they are hard to see, even with a powerful telescope. They must be very thin. Saturn has at least 9 moons.

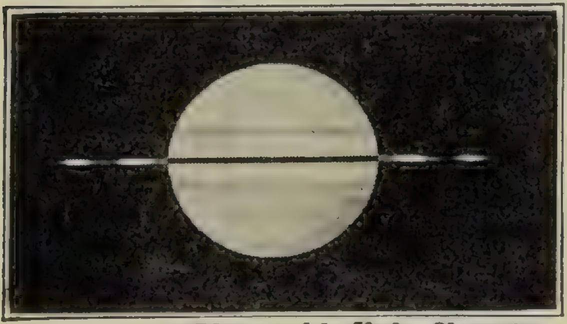
Uranus and **Neptune** are such far-off members of the sun's family that we should never have known they exist, except for the telescope. Yet each of them has a diameter more than 4 times that of the earth. *William Herschel*, a Briton of German birth, discovered Uranus in 1781. He had to work hard and long to make his own telescope, but his reward came when, one fine evening, he noted a peculiar "star." He examined it again and again for several nights, and found that it did not remain fixed in relation to the stars in its neighborhood, but changed its position. He finally concluded that it must be an undiscovered planet, and gave it its name. It has several moons.



Photograph by Yerkes Observatory.

FIG. 134, *a*.
The planet Saturn, showing the parallel bands on its surface and the rings that surround it.

While the discovery of Uranus was a triumph of the telescope, that of **Neptune** was a triumph of mathematics. After Herschel's discovery of Uranus, its orbit, or path around the sun, was carefully calculated. But as the years went on (it takes Uranus 84 years to make one revolution), the planet was found to be moving in a path slightly different from the one that had been computed for it. Were the calculations of the astronomers wrong, or is there some other body, still farther out in space than Uranus, that by the force of its gravitation changes the path of Uranus? The problem was a most difficult one, but it was solved in 1846 by two young men: J. C. Adams, of Cambridge, England, and Joseph Leverrier, of Paris. They worked independently of one another and by different methods, but they reached the same conclusion. When the telescope was turned to the place in the sky in which the calculations of Adams and



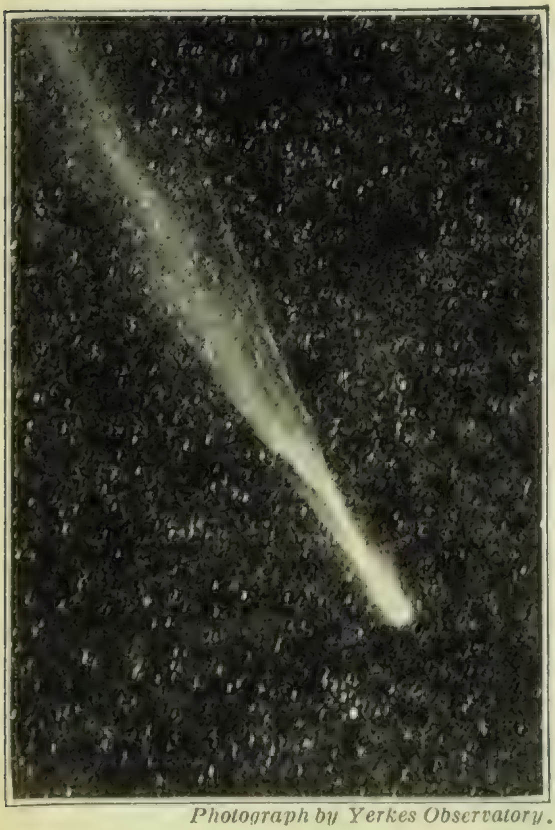
Photograph by Yerkes Observatory.

FIG. 134, *b*.
An edgewise view of Saturn's rings. Note the flattening at the poles due to the planet's rapid rotation.

Leverrier stated the unknown body should be, a new planet was discovered; it was named **Neptune.**

Neptune is indeed far away from the sun: about 30 times as far as the earth. Light from the sun, which reaches us in about 8 minutes, (see § 152), requires about 4 hours to reach Neptune. Yet Neptune revolves about the sun as the earth does, even though it requires 165 of our years to make the journey.

158. Comets.— We have every evidence that comets were a wonder and a terror to ancient and medieval peoples. Whole nations were thrown into panic when one appeared. Some people still fear them to-day. Men were accustomed to their sky, with its sun and moon, its stars and planets, and then, some night, a strange celestial visitor appeared. It had a bright head, or nucleus, and a long "tail" of light spread out behind it. The next night it was there again, but it had changed its position. Night after night it grew larger, and approached the sun. Sometimes it could be seen in daylight. Finally it rose and set with the sun. Eventually it receded from the



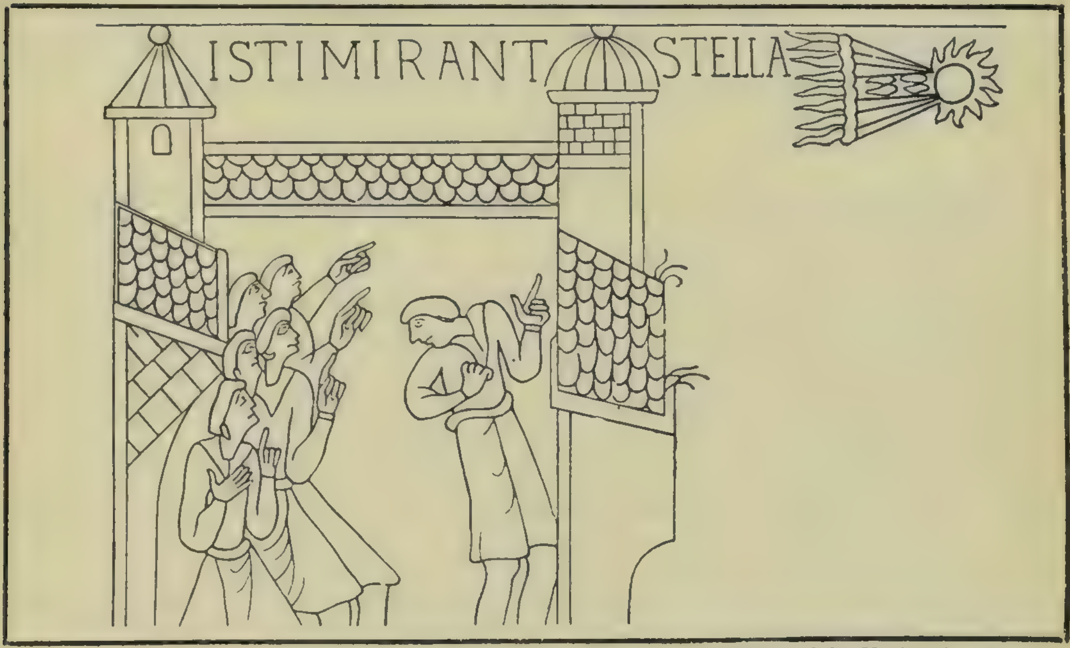
Photograph by Yerkes Observatory.

FIG. 135.

Comet Morehouse. Note the streaks for the fixed stars, produced because the camera was kept focused on the comet, which changed its position with respect to the stars.

sun, its "tail" now going ahead, that is, pointing away from the sun. Finally the comet grew smaller and then disappeared.

A comet has the appearance of a shining fog or veil. Stars can be seen shining right through it. The tail always points away from the sun.



Photograph by Yerkes Observatory.

FIG. 136.

Halley's comet in 1066 A.D., as depicted on the tapestry in the cathedral at Bayeux, in Normandy, France. This tapestry is a strip of linen 18 in. wide and 230 ft. long, embroidered with woolen thread. It illustrates in 58 scenes the events that led to the conquest of England by William in 1066. The comet of that year was considered very important, and forms scene 32 of the tapestry.

It was the work of Newton on gravitation (see § 108) which showed that a comet is a body of matter moving around the sun, as a planet does, but in a very much elongated orbit. **Edmund Halley** (1656-1742), using Newton's ideas, calculated the path of a comet that appeared in 1682, and found that the comet's path was almost exactly the path of comets that had been seen in 1607 and 1531. He decided that these comets were one and the same, and that the comet revolved about the sun once in about 75 years. Halley therefore predicted that the comet would be back again. He had no hope of seeing it himself, but he believed in his calculations. Halley's belief was justified, for the comet returned, and was at its nearest point to the sun early in 1759. It came again in 1835 and in 1910, and is expected the next time in 1985. Its periods of revolution are not always exactly the same, because it may be turned slightly from its course if it comes near the outer planets as it crosses their orbits. In Halley's time Uranus and Neptune were unknown. By looking into old records of comets astronomers find that Halley's comet probably appeared at about 75-year intervals (see Fig. 136) as far back as 240 B.C. Make a list of the years in which it might have been seen.

159. Meteors and Meteorites.— Meteors, or "shooting stars," are small fragments of matter that fall into the earth's atmosphere from outside space, and are so heated by the friction that they give off light. If several persons were to watch the sky carefully on a clear night when there is no moon, they would probably see a number of meteors. They probably reach the ground only in the form of dust and ashes so fine as to be entirely invisible. It has been estimated that 10,000,000 or more meteors reach our atmosphere daily. About November 14th they are especially numerous in the constellation *Leo*, one of the Signs of the Zodiac (see § 151). At intervals of about 33 years the display is unusually brilliant. Perhaps swarms of meteors revolve about the sun in definite orbits, and their orbits cross that of the earth. If the earth and the shooting star come to the same place at the same time, there is a collision. The shooting star, or the products formed when it is oxidized, become a part of the earth. Does this mean that the earth is increasing in size by the addition of new material from space?

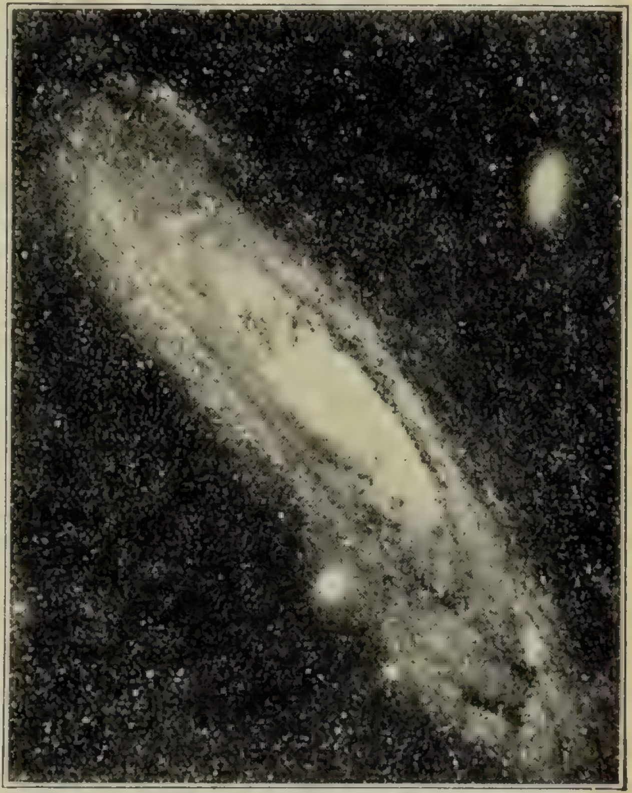
A **meteorite** is a large body that falls from space to the earth; it may weigh several hundred pounds. When seen at night a meteorite is like a ball of fire followed by a stream of light. If we are near enough, we hear a dull roar as it tears its way through the air. During its passage it usually throws off sparks and fragments of matter. Commonly the meteorite disappears, but sometimes men learn where it strikes the earth, and dig it up. Instead of falling to the earth as one body, the meteorite may burst into many pieces. The material of meteorites is usually stone, but sometimes they are made up of iron and nickel, together with combustible gases absorbed by these metals.

160. The Fixed Stars.— We have already learned (see § 151) what is meant by **fixed** stars. The sun seems to shift its position from one constellation to another because of the yearly revolution of the earth. The change in a planet's positions is due to the motion of both the earth and the planet, for both revolve around the sun. But the fixed stars are so far from our solar system that we cannot ordinarily see that they change their positions at all. However, by the most careful observation and measurement of the positions of certain stars with respect to neighboring stars, astronomers have been able to detect a slight shifting.

One cause of the changing positions of some of the stars is the earth's revolution around the sun. If two observers a considerable distance apart look at the sun at the same instant, they see it *in different directions.* By knowing the distance between the observers and the difference in direction, measured in degrees, minutes, and seconds of arc, we can calculate the distance of the sun from the earth. But when two observers get as far apart as they possibly can (how far is this, in a straight line?), there is no difference in direction of any of the fixed stars. It is only after the earth has moved for some months in its orbit, so that the distance between its positions is equal to its distance from the sun (93,000,000 miles), that astronomers have a **base line** long enough for accurate measurements. Even in the case of the nearest star, the light of which requires only (!) 4.4 years to reach us, this difference in direction is not a **degree** of arc, not even a **minute**, not even a whole **second!** In this way the distances of about 100 stars have been obtained. **Sirius**, the brightest star in the sky (see § 149) is one of the nearest: about 8.4 light-years away. Sirius has a mass about 3 times that of our sun, and is giving off about 48 times as much light.

At the present time astronomers measure the position of one star in relation to others almost entirely by means of photography. Photographs of the star being studied and of the region of sky near it are made several times during the year, and the distances of the stars in the photograph are accurately measured. Thus any apparent shifting of the star, due to the different positions of the earth in its orbit, can be obtained.

In addition to the apparent motion of the stars due to the revolution of the earth, many stars are known to have a real motion through space. Our own sun, with its family of planets, is moving in this way. Of course we cannot very well notice the motion of a distant star if it is coming **toward** us or going **from** us, even with a telescope. Why? But what the telescope cannot tell us the **spectroscope** (see § 152) can; furthermore it can tell us the **rate** of the star's motion. However, even if a star is found to be approaching our solar system at the rate of 20 miles a second (a little more than the earth's velocity in its orbit), we need not fear a collision, for thousands of years would be needed for it to reach us.



Photograph by Yerkes Observatory.

FIG. 137.

The Great Nebula in the constellation Andromeda.

Many stars which seem to be one point of light are really, when seen in the telescope, made up of two or more stars. Thus there may be double stars or triple stars, or multiple stars. These stars are not simply near one another in the sky, as the stars of a constellation are, but they are actually part of a system, and revolve about one another. The star *Mizar*, at the bend in the handle of the Big Dipper, is a double star, and the spectroscope shows that the brighter star of the pair is itself a double star. The faint star we see near Mizar is *Alcor*. Mizar is so far away that its light takes about 75 years to reach us. *Capella* is really a pair of stars; Sirius is likewise made up of two stars, both revolving about their common center of mass (see § 122). The star *Algol* (see Star Map) is of great interest because its light is **variable** in amount. Normally it is a star of the second magnitude, like Polaris, but at regular intervals it loses $\frac{5}{6}$ of its light. This change in brightness is due to the fact that Algol is really two stars, one dark and the other bright, and that the bright star is eclipsed regularly by its dark companion.

Sometimes, instead of a star, the telescope and camera show us a hazy mass of glowing material called a **nebula** (the plural is *nebulae*). The middle one of the three faint stars in the "sword" of **Orion** is a nebula. The brightest nebula in the sky is that in the constellation *Andromeda* (Fig. 137). There are nebulae in **Lyra,** in the **Great Bear,** and in **Cygnus.** There are thousands of nebulae in the heavens, some of them of enormous size.

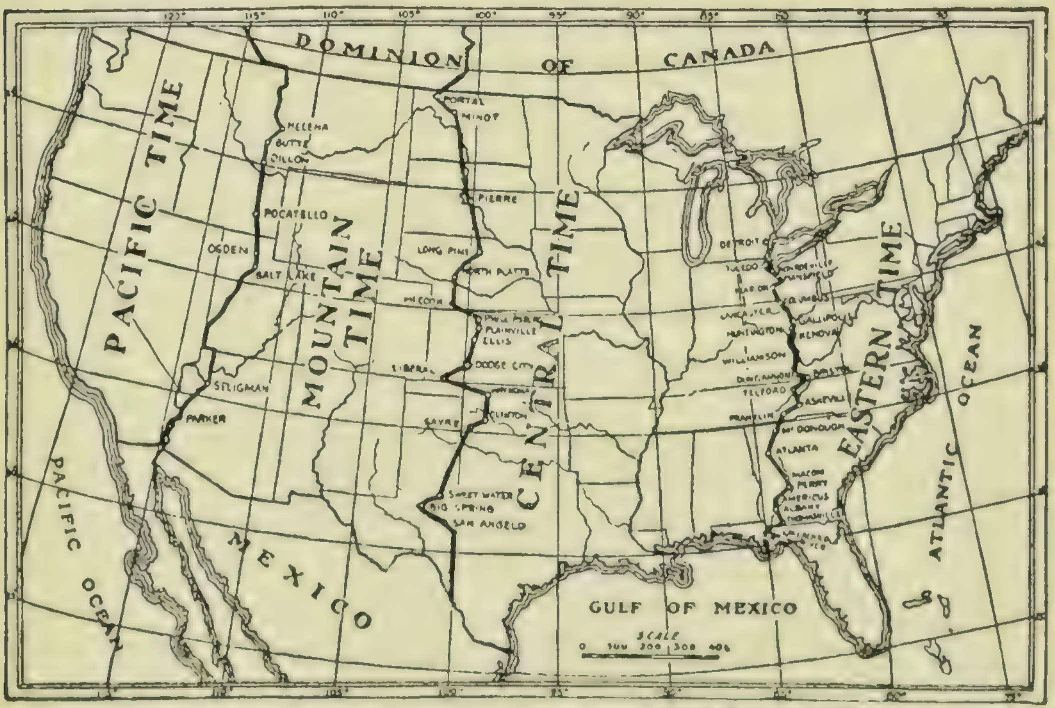
161. Time.— The measurement of time is based on the two principal motions of the earth. The **day** is determined by the earth's rotation on its axis; the **year** by its revolution around the sun. How can we know that the earth has made *exactly* one rotation, and that a day has passed? We have already learned the method (see § 151): a day is the interval of time between one passage of our meridian, as it turns eastward, across a given heavenly body and its next passage across the same heavenly body. If we select a star for the heavenly body, we obtain a **sidereal** (sī-dē′rē-ăl) **day.** If we select the sun's center as the point for the meridian to cross, we get a **solar day.** If the star and the sun remained in the same positions in the sky with respect to each other, there would be no difference between sidereal and solar days; but as the sun appears to move eastward about 1° daily (360° in 365 days), the solar day is nearly 4 minutes (3 min. 56.55 sec.) *longer* than the sidereal day (see § 147). Astronomers use sidereal time rather than solar time.

Are our clocks made to keep time by the sun? Almost, but not quite; for the solar day does not contain the same number of seconds (24×60×60) at all times of the year. The longest **day** (not daylight) of the year comes near the end of December, and the next longest near the end of June, while the last weeks of March and September have the shortest days, according to the sun. Clocks cannot be made to keep time with all these variations; hence we actually use not true solar time, but **mean solar time.** The number of seconds in a mean solar day is the *average* of the numbers in all the days of the year. The difference between true solar time and mean solar time is called the **equation of time.** It may be found in almanacs, and tells us how much we must add or subtract to change one into the other. As a matter of fact, astronomers calculate the length of each mean solar day for us, not from the sun, but from the sidereal day, which they determine by the stars.

Standard Time.— The mean solar time of any given place is called the **local time** of that place. Local time would do very well, if men travelled only north or south; for all places having the same longitude (what is this?) have the same local time. But it is different when we go east or west; in most of the United States local time is about 1 minute slower for every 12.5 miles we go west, and the same amount faster for every 12.5 miles we go east. How can a railroad run its trains safely and regularly, if every station uses its own time?

In order to get uniform time all civilized countries have adopted a system of **standard time.** The time of these countries, like their longitude, is reckoned from the observatory at Greenwich (grĭn′ĭj), England. In the United States and British America there are **four time belts,** using Eastern, Central, Mountain, and Pacific time. The **Eastern** belt uses the local time of Philadelphia, which is on the meridian 75° west of Greenwich. Since 15° of longitude correspond to 1 hour of time (see § 147), Eastern time is 5 hours slower than Greenwich time. When it is noon at Greenwich, it is 7 A.M. at Philadelphia and at all other places using Eastern time. On the Eastern side of this time belt local time may be 30 minutes ahead of standard, and on the western side it may be 30 minutes behind standard, but no place will be more than this amount from its own local time.

Central time is an hour slower than Eastern time. How much slower than Greenwich time? It is determined from the 90th meridian, which passes through St. Louis. **Mountain** time is the local time of Denver, which is in longitude 105° west of Greenwich. It is 2 hours slower than Eastern time. **Pacific** time is the local time of places on the 120th meridian west of Greenwich. This passes about 100 miles east of San Francisco. Pacific time is how much slower than Eastern time? Than Greenwich time?



From Hopkins' Physical Geography.

FIG. 138.
Standard Time Belts in the United States.

Accurate standard time is sent by telegraph each day between 11.55 A.M. and 12.00 noon to about 30,000 clocks in different parts of the country; the clocks are regulated automatically by signals from the Naval Observatory at Washington.

As a matter of fact, the time belts of the United States are not bounded *exactly* by the meridians of longitude. The points at which time shall be changed is left largely to the convenience of railroad systems, so that the change shall take place where it will make as little confusion as possible. See Fig. 138.

162. The Year and Its Seasons.— You have already learned from your study of geography what causes the seasons: spring, summer, autumn, and winter. The earth's axis always points to the north and south poles of the sky, and as the earth revolves around the sun (Fig. 139), first the north pole of the earth, and then the south pole, is turned toward the sun. When the north pole faces the sun, the northern hemisphere has *summer;* when it is turned away, the northern hemisphere has *winter*.

If the earth's axis were perpendicular to the plane of its orbit, there would be no change of seasons. But the axis is inclined 23.5° away from a perpendicular position, or 66.5° (90—23.5) to the plane of the earth's orbit. This means also that the plane of the earth's equator is inclined 23.5° to the plane of the earth's orbit. Because the earth retains this inclined position as it revolves, there are two **frigid zones,** lying between 66.5° and 90° latitude, north and south, respectively, where the sun does not come above the horizon at all for six months, and where it does not set for the remaining six months. About June 21 the sun's rays fall **vertically** at the Tropic of Cancer, in latitude 23.5° N., and about December 21 they fall vertically at the Tropic of Capricorn, in latitude 23.5° S. This is the same as saying that the sun reaches the **zenith** at noon on these days (see § 147). Between the tropics lies the **torrid zone.** In the **temperate zones** the sun never reaches the zenith, but, on the other hand, it is above the horizon a part of every day of the year.

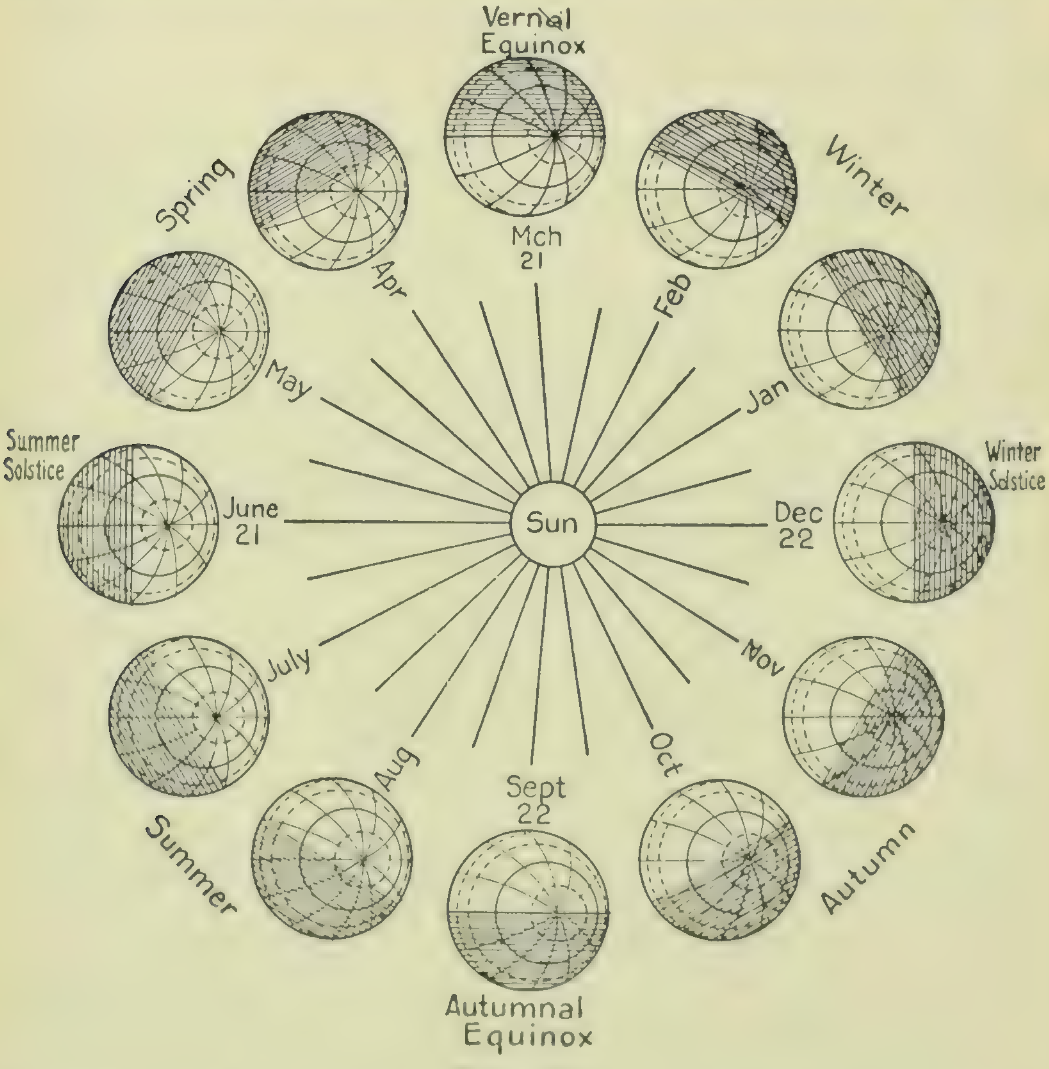


FIG. 139.

The positions of the earth with respect to the sun's light in the four seasons of the northern hemisphere. The unshaded parts represent day; the shaded parts, night. (Suggested by Hopkins' Physical Geography.)

When the sun's rays fall **vertically,** they are more completely absorbed than when they fall obliquely, and they therefore warm the earth to a greater extent. The more oblique the rays are, the less is their intensity, for they are spread out over a **larger surface** (Fig. 140). In the polar regions, although the sun is above the horizon six months at a time, its **altitude** is low, and its intensity small. In the temperate zones summer is warmer than winter, both because the sun's rays are then more nearly vertical, and because in summer the hours of daylight are longer and more sunshine reaches these zones.

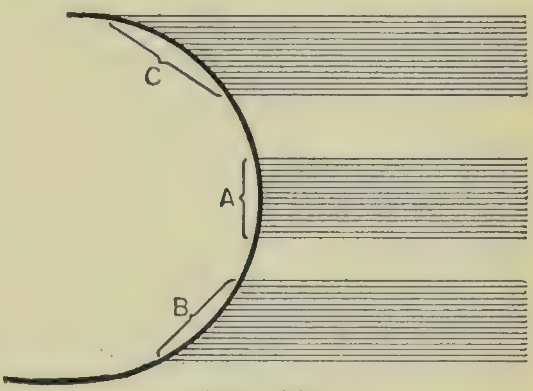


FIG. 140.
The same amount of sunlight falls on the three areas, but it is much less intense where it falls obliquely than where it is vertical.

Within one day of March 21 we say that the sun is at the **vernal equinox,** and spring begins. There is no bright star at the vernal equinox, but it is the point at which the sun's path in the heavens crosses the **sky's equator.** The sky's equator is the circle in which the plane of the earth's equator cuts the sky, and, as we have already learned, the sun's apparent path really represents the earth's orbit (see § 151). Our **common year** is the time that elapses between the sun's passage of the vernal equinox and its next succeeding passage. It is 365 days, 5 hours, 48 minutes, and 45.92 seconds of mean solar time. The **sidereal year,** or the time required for the sun to move around the heavens from a certain star and back to the same star, is about 20 minutes longer: 365 days, 6 hours, 9 minutes, and 9.54 seconds, or practically 365.25 days.

After passing the vernal equinox the sun appears to go farther and farther north of the sky's equator, until about June 21, when it is 23.5° north. This is the **summer solstice** (sŏl′stĭs). The sun then turns southward again, toward the sky's equator, and crosses it about September 23, at the **autumnal equinox.** When the sun is at the equinoxes, day and night are equal all over the earth. The sun's path is farthest south of the sky's equator at the **winter solstice,** about December 21. At the solstices the sun's daily path, due to the rotation of the earth, is almost **parallel** with the sky's equator for a week or two; hence the sun does not appear to be moving either north or south. Solstice is derived from words meaning "sun" and "standing." Equinox comes from words meaning "equal" and "night."

163. Summary.— The ancient Greeks knew that the earth is **round** and that it **rotates.**

The **diameter** of the earth must be **calculated** from its circumference.

We **find** the circumference of the earth by measuring the length, in miles, of a known number of degrees of arc.

At the equator the **speed of rotation** of the earth is 1000 miles an hour, or 17 miles a minute.

The **horizon** is the circle in which the plane of the observer cuts the sky.

The **zenith** is the point at which a plumbline, if extended, would pierce the sky.

The **north point** of the horizon is the point vertically under the north pole of the sky.

Vertical circles pass through the zenith and any two *opposite* points of the horizon. The **meridian** is the north-south vertical circle.

Altitude is the distance, in degrees, above the horizon, measured on a vertical circle. Zenith distance + altitude = 90°.

The **rising** and **setting** of heavenly bodies, and their **daily paths,** are due to the rotation of the earth.

Fixed stars remain in definite positions toward one another.

The **wandering** of the sun in the sky is due to the revolution of the earth. The wandering of planets is due to the revolution both of the earth and the planets.

The **apparent path** of the sun through the constellations (the **ecliptic**) is really the circle in which the plane of the earth's orbit cuts the sky.

The **sun** is a star of moderate size. By means of the **spectroscope** we find that it contains largely the same elements as the earth.

The **orbits** of the earth and other planets are *ellipses* of slightly varying shapes.

A **light-year** is the distance light travels in a year.

The **moon's phases** are due to the varying positions of the moon with respect to the sun and the earth.

The **moon's chief effects** upon the earth are moonlight and tides.

An **eclipse** of the sun is caused by the moon's shadow; one of the moon, by the earth's shadow.

The **known planets** revolve about the sun at distances of 36 million to 2800 million miles.

Comets are members of the solar system with very elongated orbits.

Meteors and meteorites are bodies of matter that fall to the earth from space.

Fixed stars are called "fixed" because to us they change their positions so slowly. The nearest one is about 4 light-years away.

A **nebula** is a mass of glowing star material; it may be irregular, globe-shaped, or spiral in form.

A **day** is the time of one rotation of the earth. The **solar** day is about 4 minutes longer than the **sidereal** day.

Standard time is used in place of mean solar time to lessen confusion in travel.

The **common year** is the time between two successive passages of the sun across the vernal equinox.

The changing seasons are caused by the inclination of the earth's axis 66.5° to the plane of its orbit.

164. Exercises.— 1. Why is a day divided into forenoon and afternoon instead of day and night?

2. What festival is still fixed by lunar, or moon, time?

3. Why do we not have an eclipse of the sun at every new moon?

4. Define horizon, zenith, plumbline, altitude, meridian, constellation, zodiac, fixed star, planet, light-year, and eclipse.

5. If you were weighed *on spring balances* on the earth and on the moon, in which case would you weigh more? Why?

6. What causes the four "quarters" of the moon?

7. In what season is wheat harvested in Minnesota? In Argentina? Why?

8. What would be the appearance of the earth as seen from the moon?

9. Suggest what may be the cause of a "ring around the moon." Is the ring near the moon?

10. Name the planets in the order of their distance from the sun. In the order of their size, beginning with the smallest.

11. When the photographic telescope is pointed toward a constellation and kept in fixed position for a time, the stars appear on the negative as streaks or trails instead of as points. Why?

12. When such a photograph is taken of the region near the sky's north pole, the trails of the stars, including the north star, are found to be circles. From this fact do you judge that the North Star is at the sky's north pole?

13. What daily path would a star have if you were at the earth's north pole? What path would the sun have?

14. What is the daily path of a star to a person at the equator?

15. What results would follow if the earth were to rotate twice as rapidly as now?

16. What is meant by *standard time?* When it is noon in Washington, D. C., what time is it in Chicago, St. Louis, Denver, and Los Angeles?

17. What is meant by "daylight saving"? How is it carried out?

18. There is as much sunshine in a year in the frigid zones as in the torrid zone; why is there such a difference in climate?

19. In what part of the sky will the full moon be at sunset? At sunrise?

165. Projects.— 1. Construct an ellipse showing the orbit of the earth on the scale of 1 ft. to 1,000,000 miles, and show the proportional sizes of the sun and earth. SUGGESTION: Select an open space in a field or in a city park. Drive into the ground two stakes, 3 ft. apart, for the foci (fō'sī) of the ellipse, and tie a piece of cord in a loop so that each half of the loop is 94½ feet long. Put one end of the loop over the two stakes, and with a stick in the other end of the loop trace the ellipse that represents the earth's orbit (see Fig. 128, § 152). Calculate the diameter of the sun and earth upon this scale, and represent them by disks of proper size cut out of cardboard.

2. Prepare a paper upon the sky's north-polar constellations.

3. Prepare a paper on the south-polar constellations.

4. Prepare a paper on the astronomy known to the ancients.

5. Prepare a paper on the astronomical instruments of the Chinese.

6. Prepare a paper on the methods of telling time before there were clocks.

7. Prepare a paper on the number of watches manufactured in a year in this country. SUGGESTION: Write to several of the largest manufacturers and get the data regarding their output.

8. Prepare a paper on the asteroids. Consult an astronomy.

9. Prepare a paper on the instruments in a modern astronomical observatory and their uses. Write to such an observatory for the information.

10. Make a small model to show an eclipse of the sun and of the moon and demonstrate it to the class.

11. Measure the length of the shadow of a certain post, such as a fence post, in the morning, at noon, and in the late afternoon, and determine when it is shortest.

12. Measure the shadow of a fence post at exactly noon, on a bright day if possible, every week for 3 months, and keep an accurate record of the date when each measurement was taken. Report your results, in chart form, to the class.

13. Prepare a list of the first-magnitude stars. Consult a textbook of astronomy.

14. Prepare a paper on the apparatus and measurements of modern civilized life that depend upon the fact that the North Star is near the north pole of the sky.

15. Prepare a list of the apparatus and measurements that go back to the position taken by the plumbline for their standard.

16. Arrange a debate on: Resolved that the use of "daylight-saving" time during the summer months is a benefit.

17. Demonstrate to the class the fact that the altitude of the Pole Star at any place gives very nearly the latitude of the place.

18. Construct a simple model to demonstrate to the class the inclination of the earth's axis to the plane of its orbit, and the relation of this fact to the change of seasons.

19. Prepare a chart to show the comparative length of day and night, or the time when the sun is above, and below, the horizon during the course of a year.

First get an almanac or calendar giving the time of sunrise and sunset for each day. Then make a chart 24 inches wide and 26 inches high, and leave a good margin besides. Draw, in faint pencil, 26 horizontal lines, 1 inch apart, each line to represent 24 hours. Each inch in the horizontal line will thus represent 1 hour or 60 minutes. Mark off on the top horizontal line the length necessary to represent the time from sunrise to sunset on Sept. 23. The remainder of the line will then show the time from sunset to sunrise. On the second line do the same for Oct. 7, and so on, for intervals of 2 weeks through the year. Finally put all the daytime part of the horizontal lines in red ink or pencil, and the nights in black. Interpret the chart to the class, explaining especially why the equinoxes and solstices are so called.

166. References.— GRIFFITH: *The Stars and Their Stories.* Monthly Evening Sky Map. OLCOTT: *A Field Book of the Stars.* PROCTER: *Myths and Marvels of Astronomy*; *Easy Star Lessons.* SERVISS: *Astronomy with the Naked Eye.* TODD: *A New Astronomy.* MOULTON: *An Introduction to Astronomy.*

CHAPTER XI

MAGNETS AND ELECTRICITY

167. What is a Magnet?— Ancient peoples knew that certain specimens of iron ore can draw to themselves bits of iron and steel. These specimens came to be called **magnets,** from Magnesia, in Asia Minor, where they were found. Natural magnets are also called **lodestones,** from "lode," meaning a way or path, that which *leads*. When a lodestone is suspended so that it can move freely, it comes to rest in a position which is about north and south. If a steel bar or needle is rubbed against a lodestone, it becomes **magnetized** itself, and likewise points north and south when free to move (Fig. 141). A slender bar or needle, properly mounted, is the essential part of a **compass** (Fig. 142). In the **mariner's compass** (Fig. 143) the delicate magnet is so mounted that it remains in a horizontal position, no matter how much the ship is

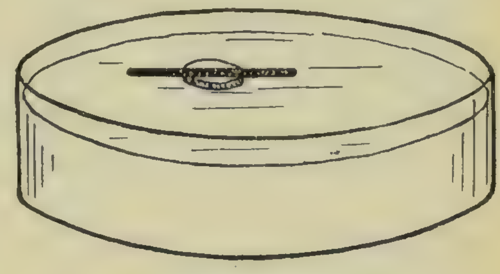


FIG. 141.
If a magnetized needle is floated upon water by means of a cork, it assumes a N-S position. The dish should not be of iron. Why not?

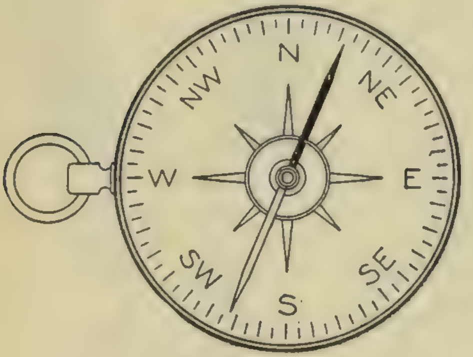


FIG. 142.
A pocket compass. When it lies in a horizontal position the needle points N-S.

tossed about. The compass was known before the days of Columbus.

If we dip a magnet (Fig. 144) into iron filings or tacks, they are attracted by both ends of the magnet, but not by the middle. If our magnet is a magnetized steel knitting needle, it acts in the same way. If, however, we break the needle in two (Fig. 145), we find that each half is a complete magnet, and that both of its ends attract iron or steel objects. If we break each half in two, we have **four** magnets, each with a north-seeking and a south-seeking end, or **pole.** Finally, if we lay the four pieces down end to end, so that the north-seeking end of one piece touches the south-seeking end of the next piece, all the four pieces will again form **one magnet,** which attracts iron filings only at the two ends.

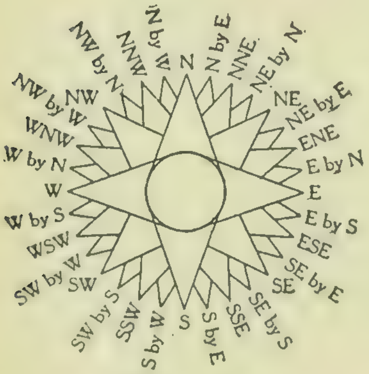


FIG. 143.
The thirty-two points of the mariner's compass.

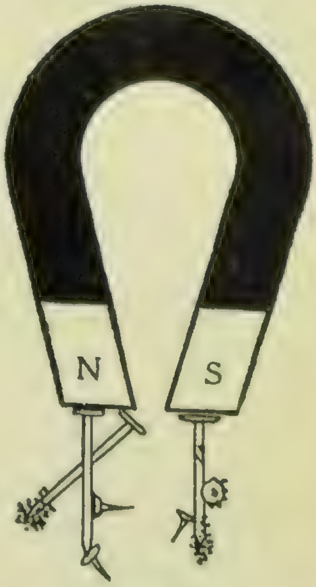


FIG. 144.
Both poles of the magnet pick up particles of iron or steel.

What we have learned thus far about magnets is that both poles attract objects of iron or steel, and that if we break a magnet, each piece is still a magnet. Substances which are attracted by a magnet are called **magnetic substances.** Such are iron and steel. The metals cobalt and nickel are magnetic, also one oxide of iron, called the magnetic oxide. Iron rust is not attracted.

Each pole of a magnet can exert an influence not only upon a magnetic substance, but upon the poles of another magnet. Thus, if we bring the north-seeking end of one magnet (Fig. 146) near the south-seeking pole of a suspended magnet, they will attract each other; but if the two north-seeking poles are brought together, there will be repulsion between them. We may thus state, as the **law of magnets**:

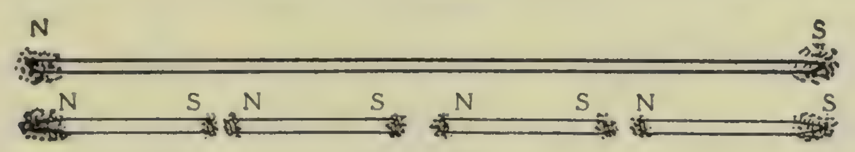


FIG. 145.
If you break a magnetized needle in pieces, each piece is still a magnet.

Like poles repel each other; opposite poles attract.

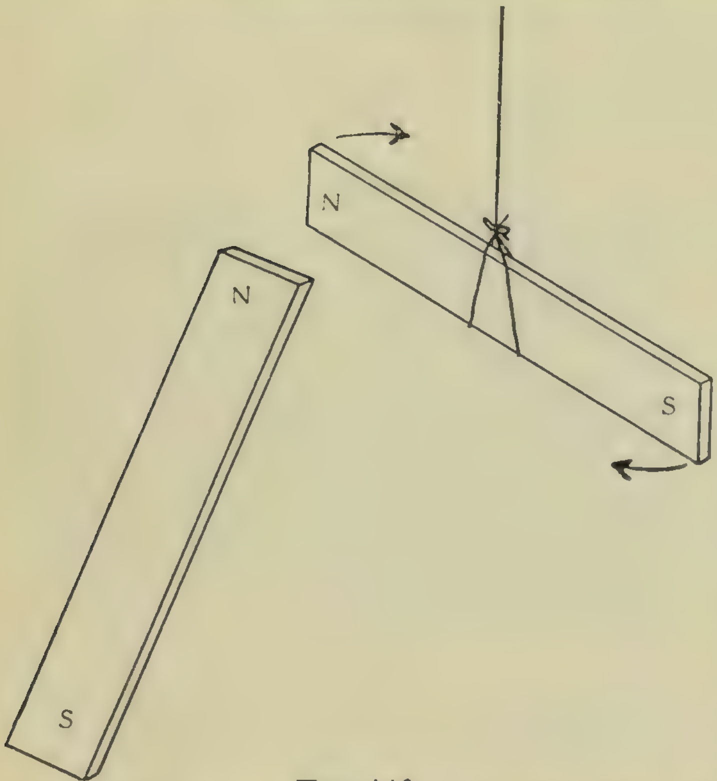


FIG. 146.
The N-pole of one magnet is brought near the same pole of a suspended bar magnet. What happens?

168. Temporary and Permanent Magnets.

168. Temporary and Permanent Magnets.—A steel magnet retains its magnetism for a long time; hence we call it a **permanent** magnet. It will, however, lose its magnetism when heated. If we hold one pole of a magnet *near, or touching*, a piece of soft iron, such as a nail, the nail itself becomes a magnet and attracts iron filings or another nail (Fig. 147). But when the soft iron is removed from the magnet, its magnetic properties disappear. Thus, while steel can be permanently magnetized, soft iron forms only a **temporary** magnet. It is important for us to notice that the magnet need not *touch* the soft iron nail in order that the nail may become a magnet. If the two are simply brought **near** each other, the nail gains this power. We say that the nail may be **magnetized** not only by contact, but **by induction.** If we could see what is happening inside an object of iron or steel whenever a magnet is brought near it, we would observe that it first becomes magnetized by induction. Then, when it is itself a magnet, its north-seeking end is attracted by the south-seeking pole of the magnet, and its south-seeking end is repelled by the south-seeking pole.

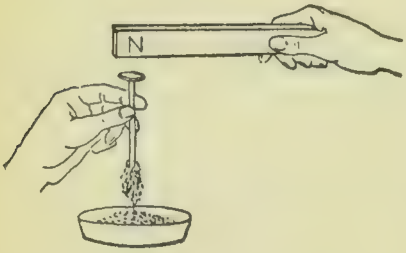


FIG. 147.
The soft-iron nail, held near either pole of a magnet, becomes magnetized by induction.

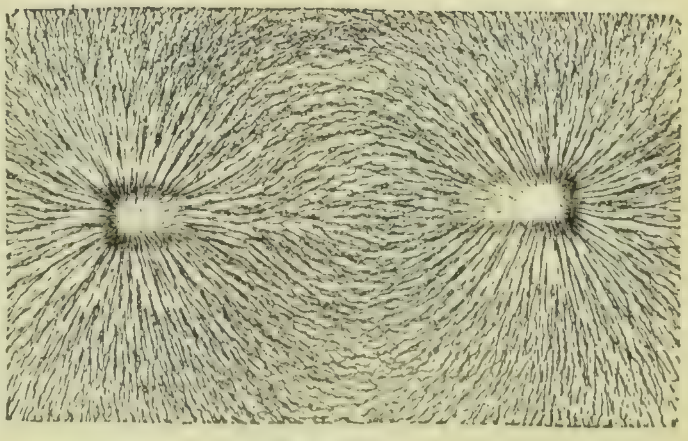


FIG. 148.
A bar magnet placed under a pane of glass or sheet of paper. The filings arrange themselves, as magnets, in the bar magnet's "lines of force."

169. The Field of a Magnet.— What conclusion can we draw from the fact that a magnet affects a piece of iron or nickel, or another magnet, without touching it? It is that a magnet affects the **space** around itself. We say that a magnet has a "region of influence," which we call the **magnetic field** (Fig. 148). This field extends in all directions from the magnet, but the intensity of the force exerted, like that of gravitation (see § 109), becomes less as the distance increases. The magnetic needle may be enclosed in glass, but this does not cut off the magnetic field. Air is not needed, for the magnet's influence is felt in a vacuum.

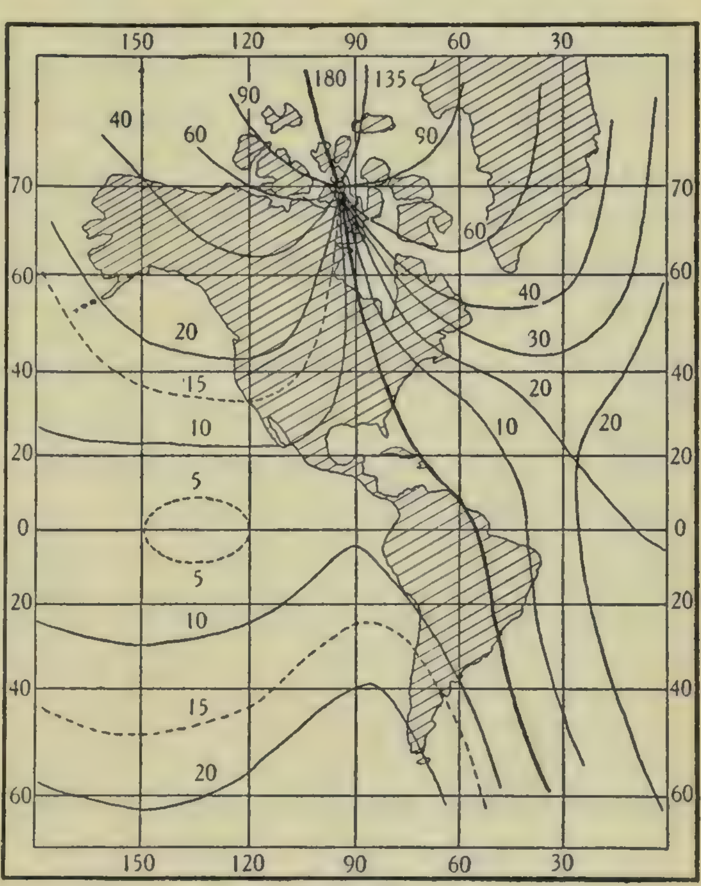


FIG. 149.

The curved lines show the directions in which a compass needle points in the Western Hemisphere and the oceans around it. Thus, at any point on the line that cuts off the eastern corner of Brazil, and marked 10, the compass points 10° west of true north. Which is the "line of no variation"?

We can readily trace the field of a magnet, as in Fig. 148, by placing the magnet under a sheet of paper and sprinkling iron filings upon the paper. Glass may also be used. When we tap the cover gently, the filings arrange themselves end to end in the magnetic field, parallel with the magnet's **lines of force**. Of course we get only a *cross section* of the field in this way. Why?

170. The Earth a Magnet.— When we consider the ways in which magnets behave toward one another, and the fact that when free to move they choose a definite position, we decide that the **earth** is itself a great magnet, with its own poles. It is to these **magnetic poles,** not to the geographical poles, that the compass needle points. The north magnetic pole is **south-seeking.**

When Columbus left Portugal, he noticed that his compass needle pointed west of true north. How did he know where true north was? When he had passed the Azores Islands, his compass pointed due north, and for the rest of his voyage it pointed **east** of true north. Columbus kept a record of these changes; but to his sailors they were a source of great uneasiness; for they thought that the very laws of nature had changed in these strange seas. The north magnetic pole is now in Northern Canada, inside the Arctic Circle. It moves westward about a degree in 15 years.

The latest determination of the position of the north magnetic pole was made by Amundsen, the Norwegian explorer, in 1905. He found it to be in latitude 70° 5′ N., and in longitude 96° 46′ W. (Fig. 149). The same explorer discovered the earth's south geographical pole in 1912.

Since the magnetic poles are not the same as the geographical poles and a compass will point due north only at certain places, we need to know the **variation** from true north to use a compass correctly. The line of no variation, for the western hemisphere, is shown in Fig. 149; likewise the lines showing the variation, or **declination,** east and west of this line. In the eastern part of the United States and Canada the compass points west of north; in the western part, east of north.

Dipping Needle.— How can one know when he has reached the region of the earth's north magnetic pole? The **dipping needle** will help. If we balance a steel needle carefully and support it so that it can swing in a **vertical** plane (Fig. 150), and if we then magnetize the needle, its north-seeking end will dip noticeably in the northern hemisphere. The farther north it is taken, the more will it dip, until the north magnetic pole is reached. Then the position of the needle will be **vertical,** the north-seeking end downward. In the southern hemisphere there is also a place at which the dipping needle becomes vertical, but the south-seeking end is then downward.

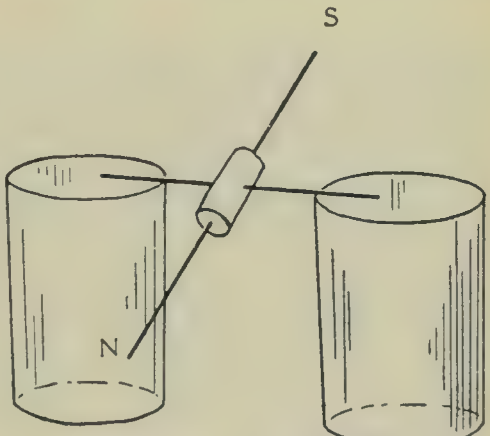


FIG. 150.
A dipping needle points downward toward the earth's magnetic pole. The nearer it approaches the pole, the more nearly vertical it becomes. How would it behave over the center of a bar magnet? Over each end?

171. Exercises.—1. If you have a compass and a bar magnet, how can you tell, without suspending the magnet, which end of the magnet is north-seeking?

2. How would a compass behave if brought near a large iron deposit? How would a dipping needle behave?

3. How would a compass behave at the earth's north magnetic pole?

4. How would a dipping needle behave at the *magnetic equator*, that is, on a line halfway between the two magnetic poles?

5. How can a ship out of sight of land be steered correctly on a bright day? On a bright night? On a cloudy night?

6. Can a compass be depended upon to give the right directions?

7. What is the advantage of making a magnet in horseshoe form?

8. Do you suppose that in a magnet the **iron molecules** themselves may be magnets, set end to end? Draw a sketch of such an arrangement, marking the poles of each small magnet N and S respectively.

9. When a steel bar is held in the direction taken by a dipping needle, pointing to the earth's magnetic pole, sharp blows on one end of the bar cause it to become a magnet. Suggest why.

10. Is the "field" about a magnet a plane, or does it extend in all directions?

11. What is the direction taken by a compass needle in Seattle? In Boston? In Chicago?

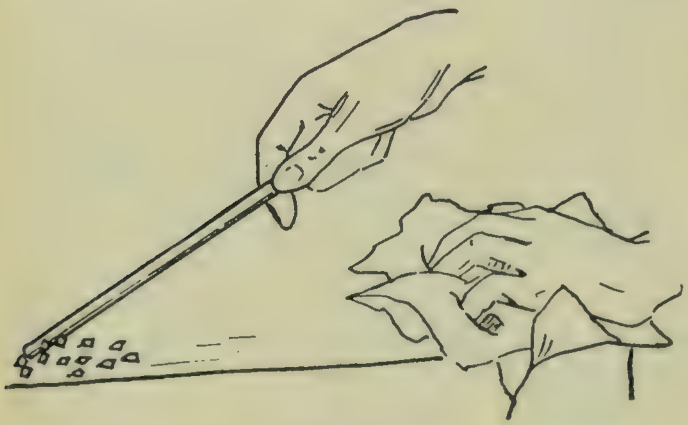


Fig. 151.
We can electrify a glass rod by rubbing it with cloth. It will then pick up bits of paper, cloth, cork, and the like.

172. Electricity from Friction. — If you rub a glass rod with silk, the rod will attract light bodies, such as bits of cloth, paper, wood, pith, and cork (Fig. 151). If you lay a pane of glass upon two books (Fig. 152), and rub the glass with silk, bits of paper or cork under the glass will be set in motion. If you rub a stick of sealing wax with fur or flannel, it will likewise attract small bodies; so will a rubber comb with which you have combed your hair.

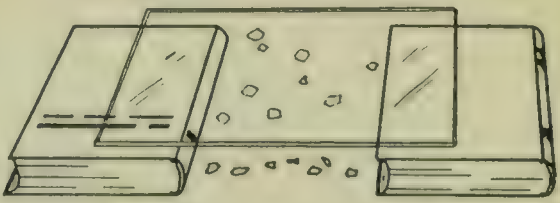
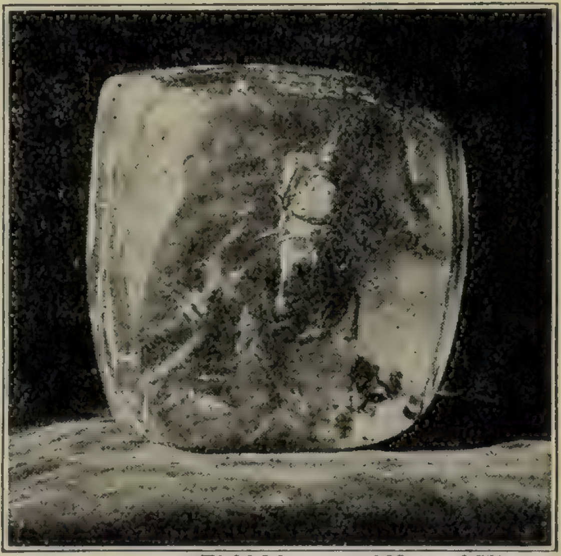


Fig. 152.
When we rub the upper surface of the pane of glass, it becomes charged, and first attracts, and then repels, the bits of paper beneath it.

If you wish to try it, you can prove that the silk, flannel, and hair become electrified as well as the glass, wax, and rubber. We say that they become **charged with,** that is to say, "loaded with," electricity. In fact, any two bodies of unlike materials are "charged" by rubbing them together; a part of the muscular energy (see § 111) used up in the rubbing is changed into electric charges.

You have probably seen **amber** beads. Amber is a **fossil** gum. Sometimes, as in Fig. 153, we find in it the remains of insects that were caught in it while it was still soft and sticky. The ancient Greeks learned that amber would attract small bodies after being rubbed. They called amber **electron**; hence our words: electric and electricity.



Field Museum of Natural History.

FIG. 153.
A specimen of amber containing the remains of an insect of long ago.

Conductors and Insulators. — Dr. Gilbert, the physician of Queen Elizabeth, found that he could electrify some bodies, but others, especially those made of metals, he could not. So he divided bodies into "electrics" and "non-electrics." He held the bodies in his bare hand while he rubbed them. If he had used a dry wooden or silk handle, he could have electrified the body of metal as well as that of glass or wax. His own body acted as a conductor, and the charge produced upon the metallic object passed through it to the earth. We now call bodies **conductors** or **nonconductors.**

Nonconductors are also called **insulators,** from the Latin, *insula,* an island. A charge formed on one end of a glass rod remains where it was produced; but if one end of a metal rod is rubbed, the whole rod is charged. The glass is an insulator, the metal a conductor; but both are "electrics." Some of the best conductors are: metals, charcoal, water vapor, and wet substances generally. Some of the best insulators are: dry air, cotton, wool, wood, silk, glass, wax, rubber, and shellac. Since the earth is a good conductor, a charged conductor will lose its charge if it is not insulated from the earth. You can **discharge** a charged body by **passing it through your hand.**

173. Electric Attraction and Repulsion.— If we bring an electrified body near bits of paper, they are first attracted, and then **repelled.** This phenomenon is studied most easily if an "electric pendulum" is used (Fig. 154). This is simply a ball of pith, or of cork, suspended by a thread which insulates it. If we hold a glass rod, charged by rubbing it with silk, near the ball, the ball is attracted to the rod. After it has obtained a charge from the rod, it is repelled. If we now bring a stick of sealing wax, charged by rubbing it with flannel, near the charged ball, the ball is attracted. Since the charged sealing wax attracts what the charged glass repels, we say that the glass and wax are **oppositely charged.**

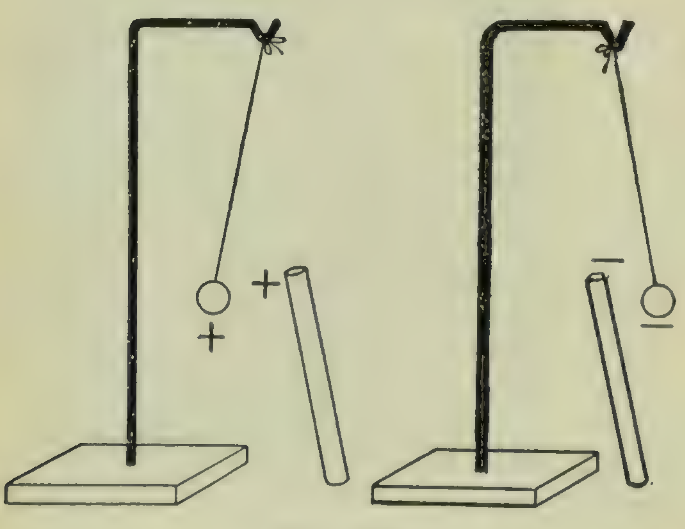


FIG. 154.
Electric pendulums. Each pith ball is first attracted by the rod, and then repelled, as it becomes charged by the rod. Like charges repel each other.

If we call the charge on the glass **positive** (+), that on the wax is **negative** (−). It will be found that the silk has received a *negative* charge by being rubbed with glass, while the flannel rubbed with wax or rubber receives a *positive* charge.

The laws of charged bodies are like those of magnets (see § 167):

1. Charged bodies attract uncharged bodies.
2. Bodies having unlike charges attract each other.
3. Bodies having like charges repel each other. The space surrounding a charged body is called an "electric field," as that surrounding a magnet is called a magnetic field.

174. What is Induction?— As we have just learned, an uncharged body, such as an electric pendulum, is charged by **contact** with a charged body. It may also be charged by **induction,** without contact, much as a piece of soft iron may be temporarily magnetized by being near another magnet (see § 168). A simple apparatus for the induction of an electric charge is an egg shell covered with tinfoil and a positively (+) charged glass rod held near it (Fig. 155), but not touching it. The two ends of the shell are electrified; an uncharged electric pendulum is attracted by either end. If the glass rod is removed, the charges disappear. We say they **neutralize** each other. We can charge the shell **permanently** if we remove one of the **induced** charges. To do this we hold the charged rod near the shell as before, and then touch with the finger the end of the shell farther away from the rod. The repelled positive charge passes through the hand and body to the earth. If we now remove, first, the finger, and then the rod, the shell will have a negative (—) charge.

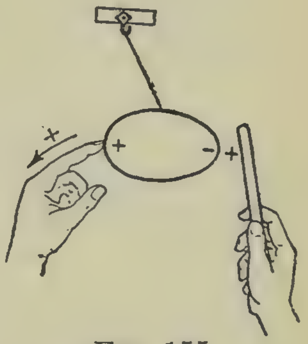


FIG. 155. Charging an egg shell (covered with tinfoil) by induction. Note that the + charge of the shell is being repelled by the + charge of the rod.

175. How Electric Charges are Stored.— The apparatus for storing electric charges (Fig. 156) is made of at least two conductors (sheets of aluminum, brass, or tin-foil) separated by a nonconductor, or **dielectric.** The nonconductor may be of glass; in **radio** outfits it is air or mica.

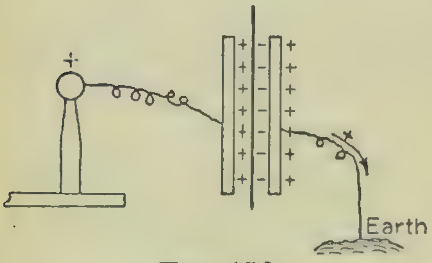


FIG. 156.
A simple electric condenser. Note that the + charge of the plate on the right is being repelled to the earth.

If one conductor is connected with a source of positive (+) charges, while the other conductor is connected with the earth ("grounded"), the negative charge of the second conductor will be held on the side of the metal next to the dielectric; but the positive charge of the second conductor will be **repelled** to the earth. Why? If we then break the earth connection, we have a large positive charge on one side of the dielectric, and a correspondingly large negative charge on the other side. We have charged the second conductor **by induction,** just as we did the egg shell in 174. We can also charge a condenser by connecting its two sets of conductors to sources of positive and negative charges, respectively. Each positive charge can hold a negative charge on the opposite side of the dielectric, up to the **capacity** of the condenser. A common form of the condenser is the **Leyden jar** (Fig. 157).

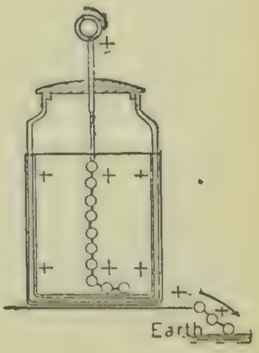


FIG. 157
The Leyden jar consists of a bottle covered to the same height, inside and out, with metal foil, and provided with a metal knob and chain reaching to the inside foil. To discharge the charged jar we break the earth connection; then use a conductor (wire or rod) with an insulating handle, and **almost** connect the outside foil with the knob. We thus get electric sparks.

176. Lightning an Electric Spark.—Benjamin Franklin was the first to prove that the charges produced in the atmosphere during a thunderstorm are exactly like those we get when we rub two different materials together. He also made the first lightning rods to protect houses.

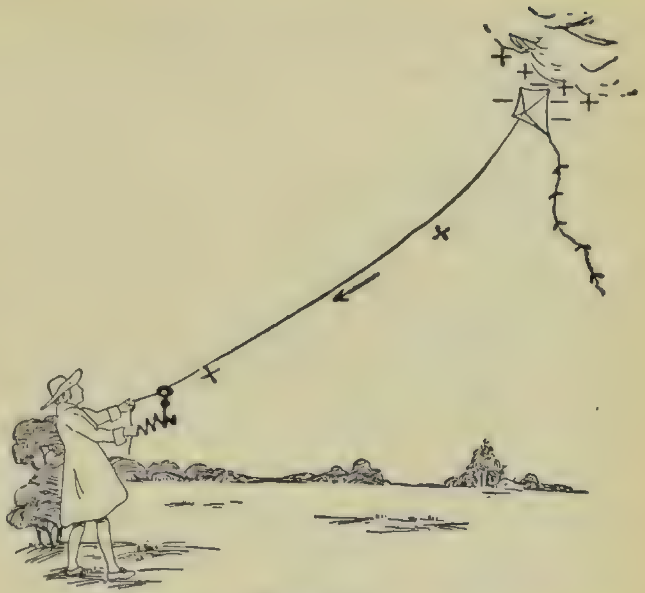


Fig. 158.
Franklin's kite was charged by induction from a charged thundercloud. Note the spark.

If in a dark room you hold your finger near a charged rod of glass or sealing wax, or a charged rubber comb, you will see that a spark discharge passes between your finger and the charged rod or comb. The sparks will be larger if you hold your finger near a charged **conductor**, for the whole conductor will be discharged at once. If we study the passage of sparks from

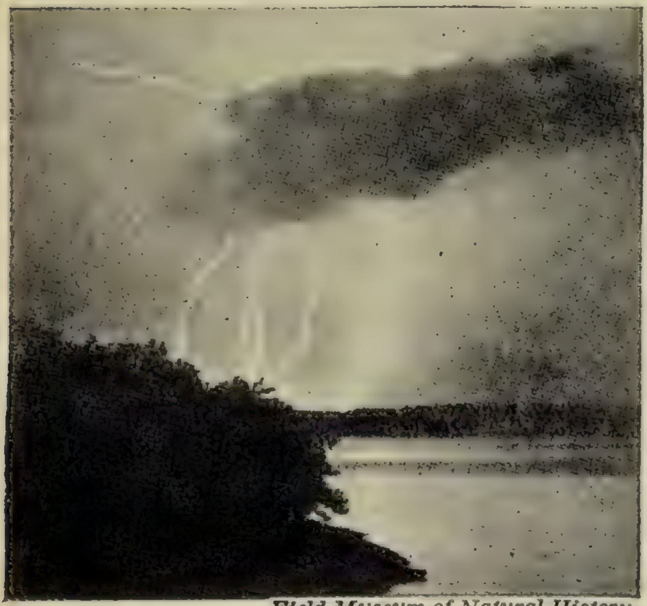

Field Museum of Natural History.

Fig. 159.
A lightning discharge.

conductors of different shapes, we find that the charge of electricity has a tendency to **stream off** from the fine points of an object, while upon blunt or rounded objects it accumulates until it is discharged as a large spark.

One day in June, 1752, when a thunderstorm was coming on, Franklin sent up a kite having at its top a pointed wire. On the lower part of the string he had a key, and the kite-string was insulated from the earth (Fig. 158). When the kite-string became wet, so that it could conduct electricity, Franklin obtained sparks from it. The sparks were exactly like those obtained by friction.

Lightning Rods.— When two charged clouds approach each other, the strain in the "electric field" between them becomes so great that, finally, the charge bursts through. This is **lightning** (Fig. 159). If the charge passes between a cloud and the earth, we say that the lightning **strikes.** The two clouds, or a cloud and the earth, with the nonconducting air between them, thus form a **huge electric condenser.**

Thunder is due to the rapid expansion and contraction of the air heated by the lightning.

As a cloud charged with **one** kind of electric charge passes over a house, it draws a charge of the **opposite** kind to the **projecting parts,** such as the roof and chimneys. The intensity of the earth's charge is likewise greater on a hilltop than in a valley and on a tree standing alone in a field than upon a tree in a forest. Commonly the leaves of a tree conduct the charge away from the tree quietly, or in streams, and so prevent a violent discharge, or **striking** of lightning. Franklin reasoned that a pointed conductor — a lightning rod — would perform the same service for a house. To be a real protection a lightning rod should have a large diameter, should have a large number of points, and should extend far enough into the ground so that it will always end in moist earth.

177. Exercises.— 1. When you comb or brush your hair vigorously in cold, dry weather, it often "fluffs out," showing that the individual hairs are repelling one another. Explain.

2. If, in cold, dry weather, you "skate" in your slippers across a woolen carpet or rug, and then bring the tip of your finger near a gas jet or other metal object, a spark often passes between your finger and the object. Explain why.

3. If you rub a stick of sealing wax with flannel, the wax receives a negative (−) charge. If the charged wax is brought near an uncharged "electric pendulum," the pendulum is first attracted, then repelled. Why? When the pendulum is repelled, what kind of a charge does it have? If, now, you bring near the charged pendulum a rubber comb which has been rubbed with flannel, and you find that the comb repels the pendulum, what kind of a charge is there on the comb?

4. Can you think of some way of finding out whether, or not, a charge is produced on the silk pad with which we rub a glass rod?

5. Should a lightning rod be separated (insulated) from the walls and chimneys of the house, or connected with them?

6. Why is it dangerous to stand under an isolated tree in a thunderstorm? Is it equally dangerous in a forest?

7. Read about the life of Benjamin Franklin. What did he do for science, for business, and for the American Colonies?

178. Electricity in Currents.— We pass "electricity" into an electric lamp to get light from it; yet it is not electricity produced by rubbing, or friction, that we use, but an electric **current.** The current comes to us along wires from a **cell** or **battery,** or from a **power house** located, it may be, many miles away. In the power house great engines run by steam, or by rushing water, (Fig. 160), or by gasoline, produce motion in an electric **generator,** or *dy-*

namo (dī′nä-mō; see § 183). The dynamo changes the rapid motion of the engine into an electric current. With this current we not only light our houses and streets, but run sewing machines, washing machines, trolley cars, motor cars, vacuum cleaners, cream separators, electric fans, and a multitude of other machines besides.

FIG. 160.

Generators at the Keokuk Dam of the Mississippi River Power Co. The dam, 4,649 feet long, extends across the river, raising the water above. Some of the water rushes through turbines, producing 200,000 horsepower of electricity. Part of this is carried to St. Louis, 137 miles away.

Electric currents are closely related to magnetism and to electric charges produced by friction, but they were discovered much later. It was not until 1786 that Galvani, an Italian, accidently discovered some effects of electric currents, and not until 1800 that Volta, also an Italian, invented an electric cell. The principle of the dynamo was discovered by Faraday in 1831.

You can make a **simple cell,** like Volta's, as follows (see Fig. 161): You need two strips of clean sheet metal, one of zinc and one of copper, each about 1×4 inches. Make a hole near the top of each, and attach a piece of bare copper wire firmly to each strip. Then tack the strips to a block. The block should be long enough to reach across the glass, so that the strips may hang in the glass.

Lay the strips aside while you fill the glass two-thirds full of **dilute sulphuric acid.** If you have only the **concentrated** acid, fill the glass about two-thirds full of cold water, and slowly pour about two tablespoons of the concentrated acid into it. In diluting concentrated sulphuric acid, we always pour the **acid into the water, never** the water into the acid, for fear of spattering the acid into our eyes.

Finally hang the metal strips in the dilute acid, join the free ends of the two wires, and look for any result on the metal strips. To determine if a current is passing through the wires, "taste the current," that is, separate the ends of the wires and hold the ends to your tongue. There is a sharp, prickly sensation.

This arrangement of two strips of metal, the dilute acid, and the connecting wires, makes up a **simple cell.** Several cells joined together form a **battery.** After you have used your cell for a minute or two, its current may become weak. If you have further need of the current, remove the metals from the acid and wash them with water; then put them back into the acid.

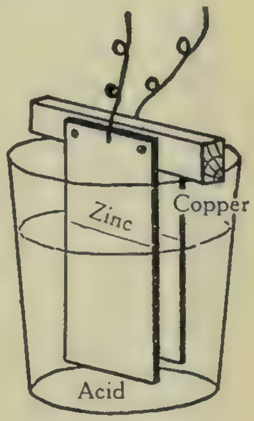


Fig. 161. The simple voltaic (vŏl-tā′ ĭk) cell consists of two metal plates, an acid solution, and wires for "closing the circuit."

If the cell is too weak to give good results, put into the dilute sulphuric acid about two teaspoonfuls of a saturated solution of **potassium dichromate.**

In making a cell we may use other materials instead of zinc and copper. We use one substance that acts readily with the acid, and one that does not. Carbon is often used in place of copper, as in the cell shown in Fig. 162. Both plates must be **conductors.** Solutions of other acids, or of **bases** (see Chap. XIV), or of certain salts (see § 179; *sal ammoniac*) may be used in place of dilute sulphuric acid.

What *causes* the current? The full explanation is rather complicated. We know that when we bring zinc and dilute sulphuric acid together, **hydrogen** is formed and the zinc is gradually "eaten" by the acid (see § 89). Much **heat** is also produced. In the simple cell, as in the hydrogen generator, the zinc is used up and will finally disappear. But while the action is going on, we get a **current** of electricity. Fig. 162 shows the direction of the current in the cell; it passes through the solution from the zinc to the copper (or carbon) plate; then through the connecting wire from the copper (or carbon) back to the zinc.

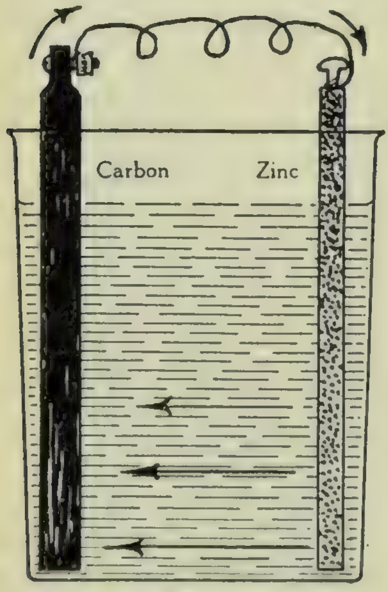


FIG. 162.
The current travels from the zinc to the carbon through the battery liquid, and from carbon to zinc through the wires.

How are cells connected? To bring the free ends of the connecting wires together, we call "making," or "closing, the circuit"; to separate them is "breaking," or "opening, the circuit." If you examine a battery of two or more cells, you will see that there are **two ways** of connecting them. One way is to join all the zinc plates to one main wire and all the copper (or carbon) plates to another wire. We "make the circuit" by joining the two main wires. The cells are then connected **"in parallel."** Another way is to connect the zinc of one cell with the copper (or carbon) of the next cell. The cells are then connected **"in series."**

179. Dry Cells and Storage Batteries.— The simple cell devised by Volta wears out very soon, but the *sal ammoniac* (săl′ă-mōn′ĭ-ăk) cell lasts longer. Sal ammoniac is the old name for a white solid the modern name of which is **ammonium chloride.** If we put into the sal-ammoniac solution a stick of **zinc** and a plate made of a mixture of **carbon** and manganese dioxide (see § 27), and connect the two plates by means of a wire, we get a current (see Fig. 163). This cell is used for ringing doorbells and *telephones*, as it gives a **strong current.** However, the current lasts only a short time. We keep the liquid sal ammoniac cell in a glass jar; but a **dry cell** is enclosed in a **zinc** jar or box, the inside of which serves as the zinc plate. The carbon plate is in the middle of the jar, and the space between the two plates is filled with a paste made of sal ammoniac, manganese dioxide, charcoal, and water (Fig. 163). The cell is closed, so that the water cannot evaporate. Is it really a "dry" cell?

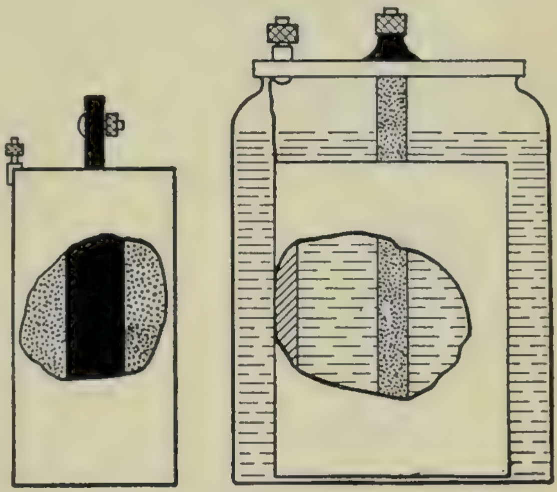


FIG. 163.
The cell on the right contains a solution of sal ammoniac, a stick of zinc, and a hollow cylinder of carbon. The smaller cell is a dry cell.

Storage Cells.— The current used to propel an electric automobile, and to produce the spark needed to explode the mixture of gasoline vapor and air in an ordinary automobile (see § 112), usually comes from a **storage battery** (see Fig. 164). A simple storage cell consists of two lead plates hung in dilute sulphuric acid. The lead is best in the form of a **grid,** to give it a large surface. To **charge** a storage cell, we pass a current through it. The change that takes place in the dilute acid is what we should expect from our study of § 99: hydrogen and oxygen are produced. However, only the hydrogen is set free; the oxygen combines with the lead of one of the plates to form a dark substance called **lead peroxide** (see § 29).

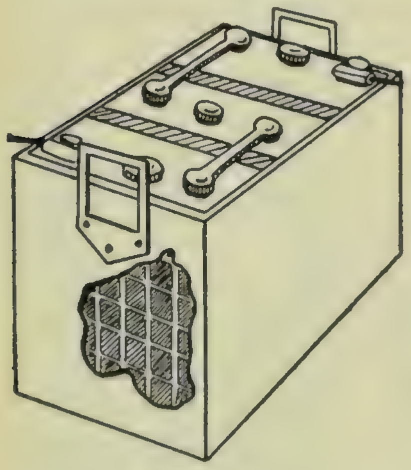


FIG. 164.
A storage cell is charged by the current, and can then be used as a source of the current.

After a storage cell has been charged, we can use it as a source of the electric current, just as we can any other cell. We have only to **complete the circuit.** The lead peroxide then loses some of its oxygen. As this change takes place, **energy** is set free and appears as an electric current. We do not really store **electricity** in a storage battery; but we change electricity to **chemical energy,** and store that. Then, when we want to use electricity, we get it from the chemical energy we have stored away.

180. How a Dish is Electroplated.— If you dip a clean, steel knife-blade into a solution of *blue vitriol* (copper sulphate), it will be covered with a bright deposit of copper. Try this. The plating of copper is, however, easily rubbed off. To make a deposit that will adhere firmly we use the current.

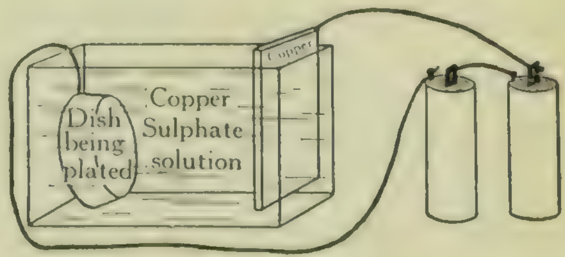


FIG. 165.
We copperplate an iron dish by hanging it at the pole by which the current leaves the solution.

We have already learned (§ 99) what the **electrolysis** of water is. When a current of sufficient strength is passed through water containing a little sulphuric acid, hydrogen is formed at one pole and oxygen at the other. If we pass a current through a solution of blue vitriol, **copper** will be formed at one pole and oxygen at the other. If we hang an iron dish at the pole at which copper is deposited (Fig. 165), and continue passing the current, the dish will be **electroplated** with copper.

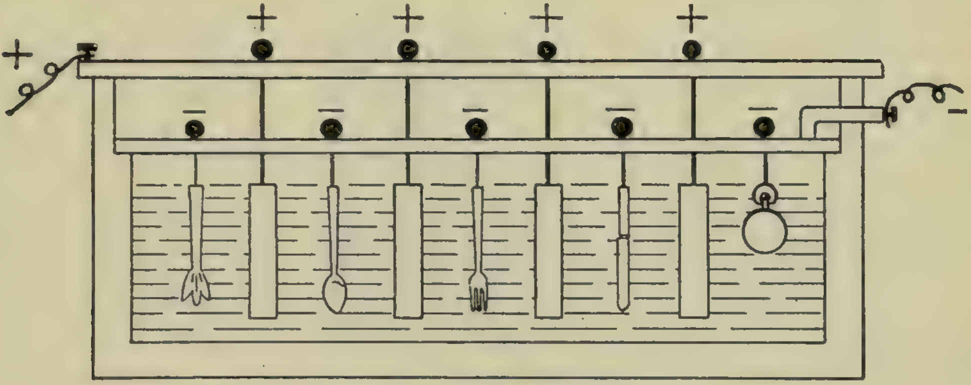


FIG. 166.
How objects may be silverplated.

The copper sulphate in the solution will soon disappear, because all of its copper will be deposited on the dish; but if we hang a sheet of copper at the **opposite** pole, copper sulphate will be formed as fast as it is used up.

The **silverplating** of spoons and other objects (Fig. 166) is carried out in a similar way. The solution contains a silver compound, instead of a copper one. A bar of silver hung at one pole wastes away, but an equal amount of silver is deposited on objects hung at the opposite pole.

Why are objects plated at all? Name some that are silverplated; some that are copperplated; some that are nickelplated.

181. Magnets Made from Currents.— If you fasten the two wires of your simple cell together, that is, "close the circuit," and hold the wire so that it is **parallel** with a compass needle (Fig. 167), the needle will not remain in a north-south position, but will turn part of the way around. We conclude from this that a wire carrying a current is surrounded by a **magnetic field** (see § 169). If this is so, then we ought to be able to magnetize a knitting needle by means of a wire carrying a current, and such a wire ought to pick up iron filings just as a magnet does. Carry out the following **experiments:**

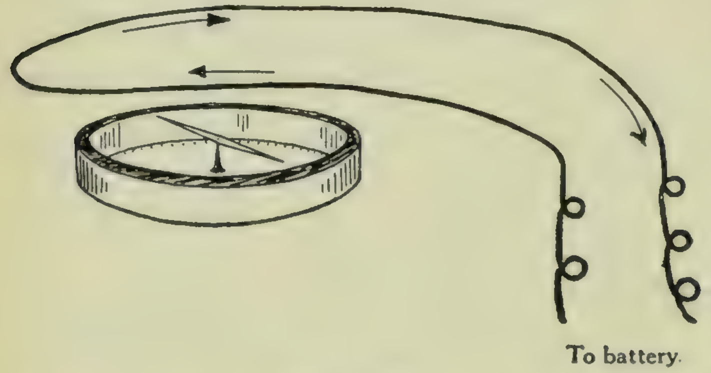


FIG. 167.
When a wire carrying a current is held in a N-S position near a magnetic needle, the needle is turned from its N-S position because of the magnetic field around the wire.

(1) Cut off a piece of covered (**insulated**) copper wire about a yard long, and remove about an inch of the covering at each end. Scrape the bare end of the wire clean with a file or knife; then wind as many turns of wire as possible about a pencil. When you remove the pencil, you will have a **coil.** Inside the coil place an unmagnetized knitting needle, and connect the bare ends of the coil with the wires of your simple cell (Fig. 168). After a few minutes take the needle out, and test it to see if it is a **magnet.** To get a stronger current use a **dry cell.**

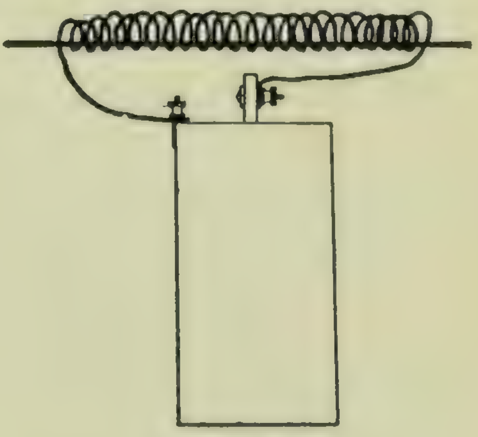


FIG. 168.
A steel wire or needle is magnetized by being placed within a coil of wire carrying a current.

(2) Hold some fine iron filings against a bare wire carrying a current from a dry cell; are any of the filings attracted? Do you think that a wire carrying a current is a magnet, or not?

182. Electromagnets.— Since a conductor carrying a current is surrounded by a magnetic field, we should expect that a soft-iron **core** placed inside a coil will become a temporary magnet, just as when it is in the field of a bar magnet (see § 168). Such a magnet is called an **electromagnet** (Fig. 169). The coil must be made of insulated wire, so that the successive turns will not touch one another; otherwise the current will not pass through all the wire, but will be "short circuited." The greater the number of turns in the coil, the stronger the magnetic field, and the stronger the electromagnet. A core made up of a bundle of small iron rods or wires makes a much stronger electromagnet than one in a single piece. But as soon as the circuit is broken, the electromagnet loses its magnetism.

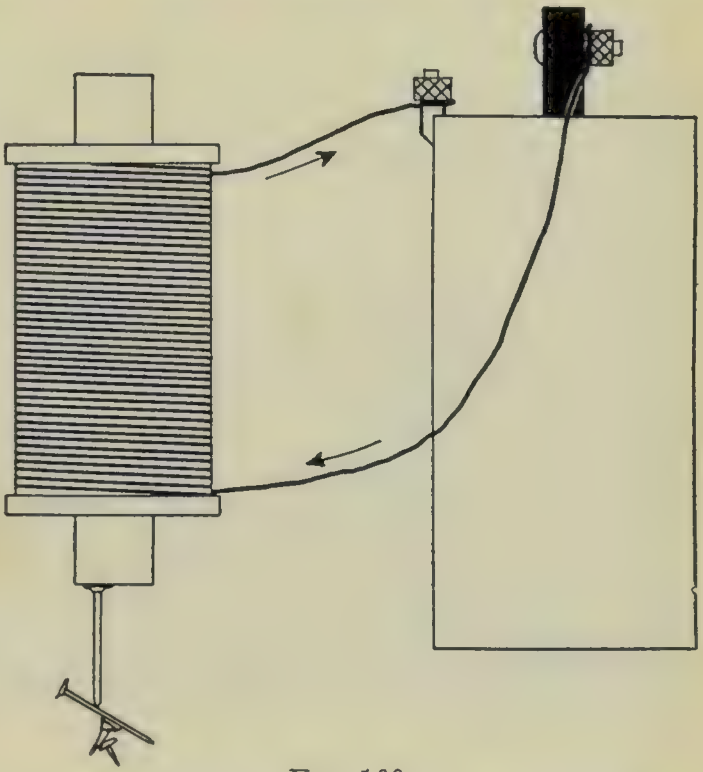
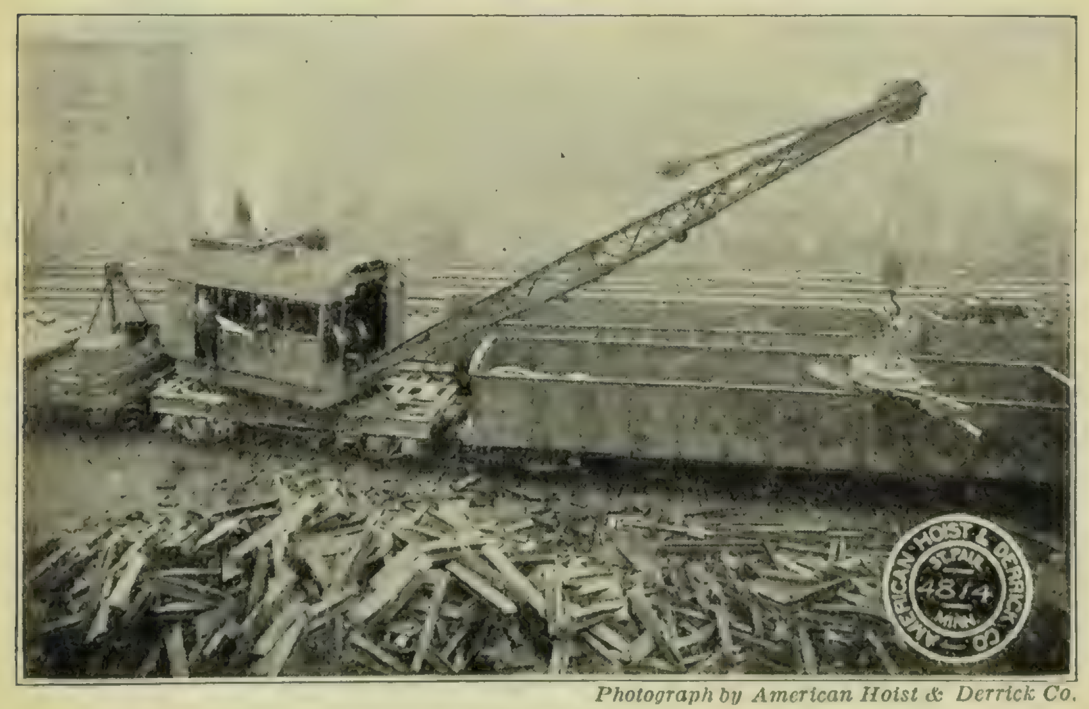


FIG. 169.
A bar of soft iron placed inside a coil of insulated wire carrying a current becomes an electromagnet.

Telegraph instruments, telephone bells, electric doorbells, fire alarms, and many other devices are operated by electromagnets. A very interesting use is in the handling of large quantities of scrap iron and steel (Fig. 170). Instead of picking it up piece by piece we use a great **steel arm,** or **crane,** at the end of which is a powerful magnet. When we wish the magnetic crane to pick up the iron, or steel object, we turn on the switch that allows the current to flow through the coil of the electromagnet. When we wish the load to be dropped, we **break** the circuit. The soft-iron core at once ceases to be a magnet, and **gravity** pulls the load down.



Photograph by American Hoist & Derrick Co.

FIG. 170.

The magnetic crane is a huge electromagnet that can pick up scrap iron and iron and steel objects and drop them where they are wanted.

Could an electromagnet be used to pick out the magnetic oxide of iron found in sea sand? To **sweep up** the steel chips and turnings on a factory floor?

183. How an Electric Bell Works.— The electric doorbell is a great convenience, for it can be placed almost anywhere, and its wires can go around corners and through walls. Examine such a bell, and compare its parts with those of Fig. 171.

Find the **battery,** or other source of the current, and trace the circuit to the **push button.** Then trace the circuit through the **coil** of the electromagnet, the **spring** attached to the piece of iron (the **armature**) and **hammer,** the metal **stop,** and back to the battery again.

At the push button the circuit is broken, and the current cannot go to the electromagnet. But if we press the button, we **close** the circuit. The current then passes through the coil, and the core becomes a **magnet** and draws to itself the iron **armature** and the hammer attached to it. As a result the hammer strikes the bell.

At this point another interesting result follows. When the armature is drawn forward, the circuit is broken, for the armature no longer touches the metal stop. When there is no current in the coil, the core ceases to be a magnet, and no longer attracts the armature. The spring then throws the armature back against the metal stop. If you are still pressing the button, the circuit will be closed once more, and the operation will be repeated.

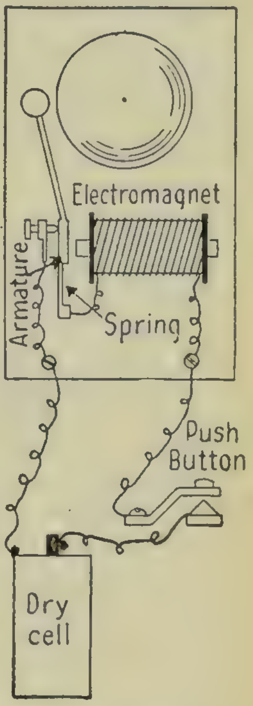


FIG. 171. The electric bell has a circuit that is made and broken rapidly at the armature of the electromagnet, whenever we push the button.

The ringing of an electric bell is thus a **series** of rapid sounds: the hammer is drawn against the bell, thrown back, and drawn forward again, many times every second.

184. The Electric Telegraph.— Few inventions have done so much for modern life as the telegraph. If the telegraph system is working properly, we can send a message to a distant city, and get an answer back before we could **write** a letter, not to speak of having it delivered. The telegraph instrument, like the electric bell, contains an **electromagnet.**

Examine a **key** and **sounder** instrument and compare its parts with those shown in Fig. 172. In the doorbell there must be a wire connection each way, but in the telegraph the "return circuit" is through the **earth** itself. How does this affect the cost?

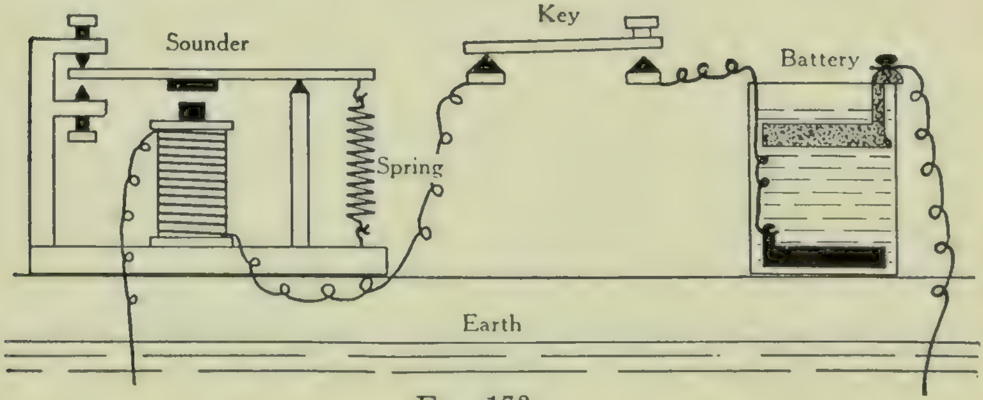


FIG. 172.
The **electric telegraph** has an electromagnet that pulls down the sounder when the operator presses the key.

The **key** of the telegraph corresponds to the **push button** of the doorbell: it "closes" and "breaks" the circuit. When the operator presses upon the key, the electromagnet under the sounder pulls down the iron **armature** of the sounder and stretches the spring at the end of the sounder. There is a sharp **click** as the sounder strikes its stop. When the operator releases the key, he breaks the circuit, so that the electromagnet loses its power; the spring then pulls the sounder up against the upper stop. If there is a very **short** interval of time between the two clicks, the operator receiving the message knows that a **dot** is meant; if a longer time, he knows it is a **dash.** The telegraphic alphabet, or **code,** is made up of short and long clicks, which mean dots and dashes. In the original telegraph, as made by Morse in 1832, a moving strip of paper was placed under the sounder, and dots and dashes were printed on the paper. The "printing telegraph" is rarely used now in regular telegraphy, for messages are taken much more rapidly by ear. Was it easy for Morse to get his invention into use? Why?

THE MORSE ALPHABET

a - —
b — - - -
c - - -
d — - -
e -
f - — -
g — — -
h - - - -
i - -
j — - — -
k — - —
l ——
m — —
n — -
o - -
p - - - - -
q - - — -
r - - -
s - - -
t —
u - - —
v - - - —
w - — —
x - — - -
y - - - -
z - - - -
& - - - -
, - — - —
? — - - — -
. - - — — - -
1 - — — -
2 - - — - -
3 - - - — -
4 - - - - —
5 — — —
6 - - - - - -
7 — — - -
8 — - - - -
9 — - - —
0 ——

CHANGES IN THE CONTINENTAL CODE

c — - — -
f - - — -
j - — — —
l - — - -
o — — —
p - — — -
q — — - —
r - — -
x — - - —
y — - — —
z — — - -
& (not used)
, - — - — - —
? - - — — - -
. - - - - - -
1 - — — — —
2 - - — — —
3 - - - — —
5 - - - - -
6 — - - - -
7 — — - - -
8 — — — - -
9 — — — — -
0 — — — — —

185. Currents Made from Magnets: the Dynamo.—On a small scale we can produce an electric current in a cell, or *battery* of cells (§ 179), but for the larger uses of modern life we need more economical and more powerful generators, or **dynamos.** To understand the principle according to which a dynamo works we must go back to the study of the electromagnet (§ 182). In an electromagnet we have a **coil** of insulated wire and a **core** of soft iron inside it. When we pass a current through the coil, the soft-iron core becomes a **temporary magnet.** This is due to the fact that the iron is in the magnetic field which surrounds the coil. Can we **reverse** matters, and from a magnet and a coil of wire get a **current?** Yes, if we *keep the magnet in motion* (Fig. 173). As each turn of wire in the coil cuts the field of the magnet, a current is set up in the wire.

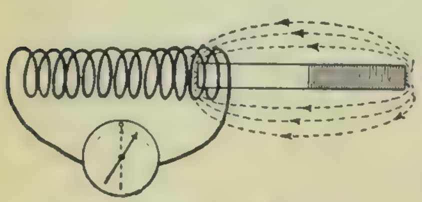


Fig. 173.
When a magnet is kept moving in a coil, a current is produced in the coil.

Instead of moving the magnet within the coil, it is better to keep the magnet stationary, and to turn the coil through the magnetic field (Fig. 174). This is the principle of the magneto-electric machine, or **magneto,** and the **dynamo.** In the magneto the magnet is a **permanent** one; in the dynamo it is an **electromagnet.**

A dynamo, or **generator,** is, then, a machine in which coils of insulated wire are made to revolve rapidly through the fields of powerful electromagnets (Fig. 175). The coils and the iron frame to which they are attached are called the **armature.** The currents generated in the coils are drawn off, as rapidly as they are produced, by "brushes," and are collected in two large wires which form the **poles** of the dynamo.

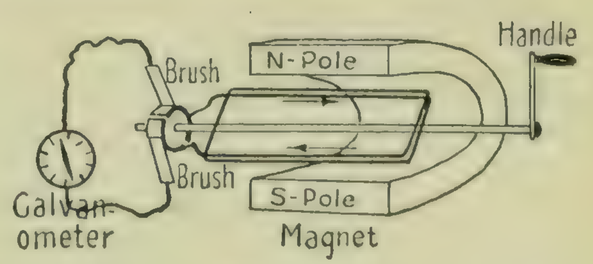
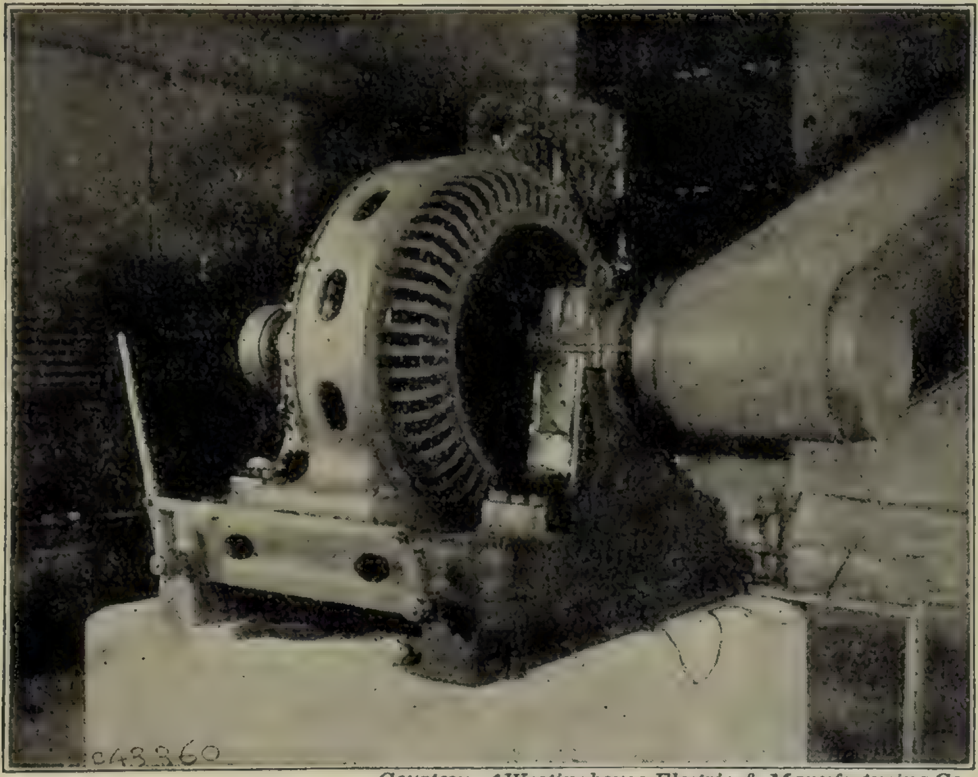


Fig. 174.
Principle of the magneto and the dynamo. A coil of wire is turned in the field of a magnet.

Some dynamos have **commutators,** or rings, that cause the series of **waves** which we call the "electric current" to flow in **one direction.**

We call such a current a **direct** current. More commonly the generator produces a current which flows in one direction for one instant, and then in the **opposite** direction, changing its direction, say, 60 times in a second. Such a current is called an **alternating** current.

In Fig. 175 a steam engine is used to drive the generator; we may also use a gasoline engine, a water turbine, or a windmill as the source of power. How is the current generated in a Ford car? In other gasoline cars?



Courtesy of Westinghouse Electric & Manufacturing Co.

FIG. 175.

Generating electricity by the energy derived from steam. The belt from the steam engine (right of generator) makes the armature revolve in the fields of the electromagnets.

186. Electric Power from Water Power.— In your study of the geography and early history of this country you no doubt learned that many of the rivers which empty into the Atlantic Ocean have falls or rapids at a certain distance from the ocean. At many of these the settlers built **mills,** and towns grew up around the mills. Name some of these towns. The mills were built at the waterfalls, because the rushing water could be used to turn the mill machinery. Afterwards **coal** came into general use, and men neglected water power and built their mills and factories where the coal supply was cheap and abundant. Can you name some manufacturing towns built for this reason?

In our day the desire for **electric power** has brought water power back into importance; for the energy of the rushing stream can be turned into a current of electricity (Fig. 176), and then sent long distances over wires, and used to produce heat and light and to do work. A dam in a river or at the outlet of a mountain lake can be used for the same purpose, because the water at the bottom is forced out in a powerful stream by the pressure of the water above it. Thus **Niagara** furnishes power not only for many electric manufacturing processes, but for the lighting of cities like Buffalo and Rochester, and for propelling, lighting, and heating trolley cars in all the country near it. The **Keokuk** dam (Fig. 160) furnishes power to St. Louis and to many towns nearer by. The Gatun dam of the **Panama Canal** generates the light and power for operating the locks of the canal. The great dam at **Assouan,** in Egypt, is likewise of enormous benefit to the region about it. All this new source of power became available to the world because of the inven-

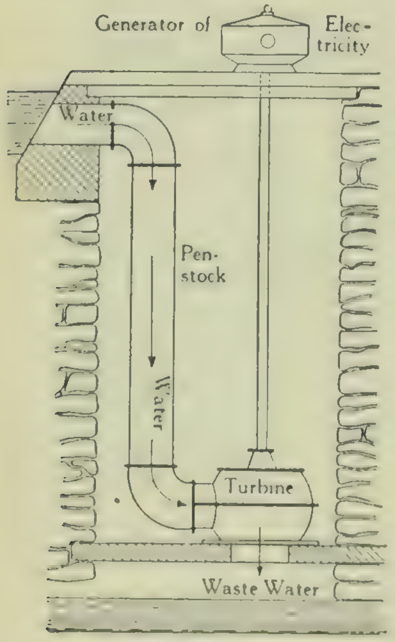


FIG. 176.
A turbine. Water from a higher level falls through a **penstock** against the **guides** of the turbine. The guides direct the rushing water upon the **blades,** causing them to revolve rapidly. The **whirling** turbine turns the **shaft** and the **generator** attached to it.

tion of the dynamo. By means of it mechanical power can be stored as electricity and carried along wires to places where it can be used to better advantage.

187. How Electricity Produces Motion. — We go to great trouble to get an electric current; but as you think of it, you will realize that we really do not want electricity for itself; we want it for what we can do with it. Like money, it is important because we can exchange it for so many things. We want electricity to heat and light our houses, schools, and factories, and to light our city streets. We also want power to move trolley cars and our house and factory machines. The device by which we get back **motion** in exchange for the current is the **electric motor.**

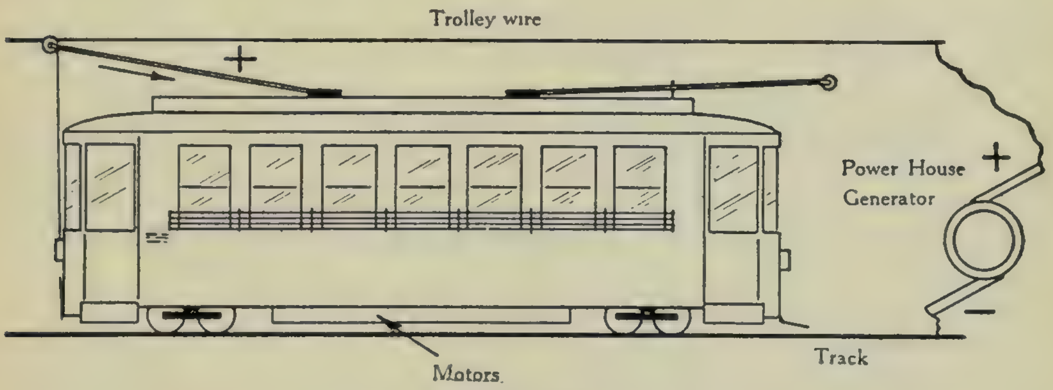


FIG. 177.
The trolley car is driven by motors which get their current from a distant power station.

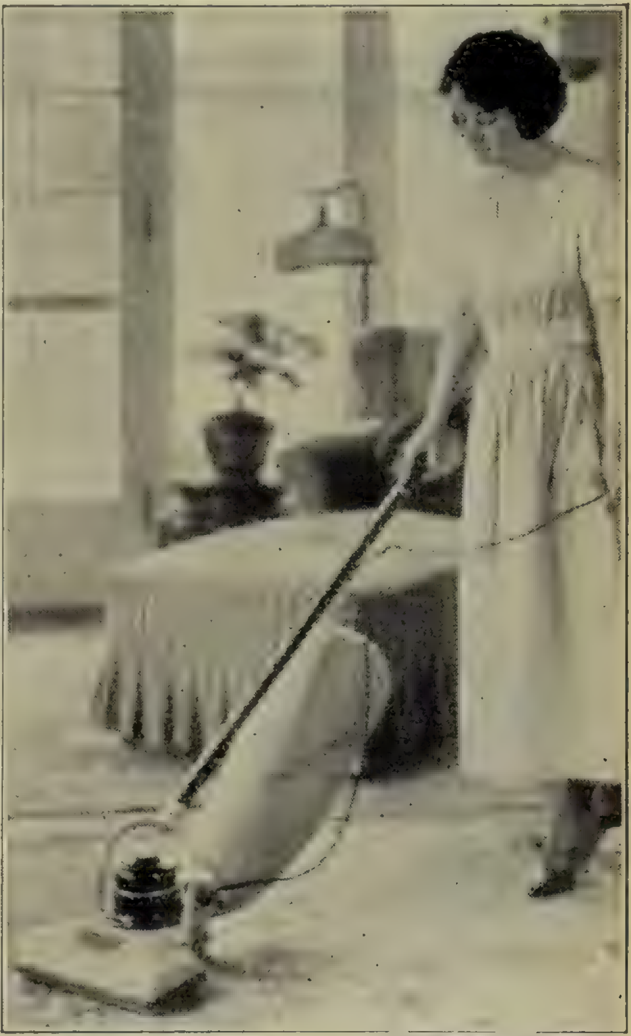
A motor has almost the same construction as a dynamo, but its work is the **reverse** of that of the dynamo. A dynamo changes energy of motion into an electric current. The work of a motor is to change the electric current back into motion. In the dynamo we turn coils of wire (the armature) in the fields of electromagnets and thus generate a current. In the motor we pass the current from some outside source into the armature and electromagnets, and thus cause the armature to revolve. Whatever machine we attach to the armature can likewise be made to revolve.

The diagram of a trolley car (Fig. 177) illustrates the action of a motor. The motor is generally under the car. The current from the power house enters through the trolley wire and pole, and goes to the motor. Sometimes a **third rail** carries the current to the motor. The current returns from the motor to the power house through the **car track,** and thus completes the circuit.

188. Electricity in the House.— It is difficult for those who are now of school age to realize how recently the electric current came into use in our houses. First, it rang our doorbells. Then, after some years, it came into a few houses to bring telephone messages. Then followed its use for lighting. It is only now coming into general use for power and in the radiophone. Its general use for heating and cooking is not yet here.

Who could have imagined that the housewife would **sweep** by the aid of electricity, or **wash clothing** in an electric washing machine, or **iron** clothes with an electric iron? Yet these machines are in many homes.

The electric **vacuum cleaner** (Fig. 178) consists of a "suction" apparatus and a long handle to direct it over the floor. A **motor** produces the suction. In some forms of vacuum cleaners there is a **brush** much like that of a carpet sweeper. There is also a **bag** of fine silk for catching dust, while letting air pass through. A long **slot** fits tightly against the floor, so that when the motor is running and producing a "vacuum" inside the cleaner, air cannot come in at the **side**, but must be drawn **through** the rug or other material upon which the slot is resting. As the machine draws air rapidly through a rug, it brings the dust with it, and cleans the rug. It can also be used for draperies, mattresses, and similar articles. It cleans more thoroughly, with less damage, than other methods of cleaning. Why is it not easy to use the vacuum cleaner on a bare floor?



Courtesy of Hoover Co.

FIG. 178.

The motor of the vacuum cleaner reduces the pressure of the air inside the cleaner. The outer air rushes in, carrying the dirt with it.

You will see at once that in using the vacuum cleaner we are not really "cleaning by electricity." We are creating a strong **current of air**; this removes the dust. The motor is run by an electric current, but we might use other sources of power. This is true also of the **electric washer**; we commonly use a **motor** run by electricity; but one run by a gasoline engine or a water motor could be used. See Fig. 234.

The electric washer is a machine for forcing the clothes through water, or water through the clothes. The tub and wringer are kept in motion by the motor. The laundress gets rid of the hard work of rubbing and wringing. If she has **electric irons** as well, which she can use constantly without having to stop to change them, and has a **drying press,** or "mangle," for straight towels and other plain linen, she can avoid much of the drudgery of the old-time washday.

The use of electricity is extending not only to the city dweller, but also to the farmer. Many modern farms have electric lighting systems run by generators which are operated by gasoline engines. The electric power thus brought to the farm is also used for the operations of washing and cleaning.

189. How Electricity Produces Heat.— Review § 45. In all the common forms of electric heating devices, such as stoves (Fig. 179), toasters, and flat-irons, you will find a wire, usually wound in coils, or bent in many turns, so as to give a large heating surface. When you turn on the current, the wire becomes hot. Electric heaters depend upon the fact that *some materials conduct the current better than others.* We bring the current to the *nichrome* of the heating unit (see §45) through a *copper* wire. The nichrome becomes very hot; the copper does not. Both are *conductors;* but in the nichrome the current meets with greater **resistance** than in the copper. A great deal of the energy of the current is changed into the energy of moving molecules: **heat.** By selecting a material with the right amount of resistance we can use

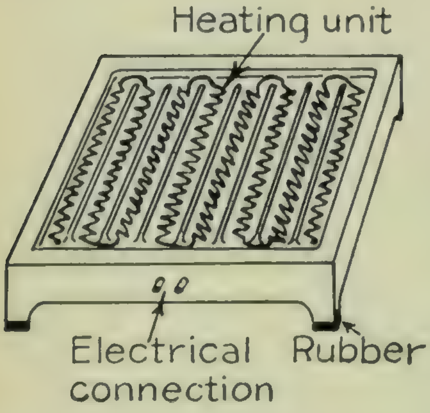


FIG. 179.
The Heating Unit of an electric stove.

the current to produce heat. If possible, carry out the following experiment:

To the binding posts of a good dry cell (Fig. 180) attach two pieces of bare copper wire of ordinary thickness (No. 16 or 18), about 3 inches long. By means of forceps (**not the hands**) bring the free ends of the wires together, so that the current can flow through them for a moment. Do the wires become hot?

Now separate the wires about an inch, and **with the forceps** lay a piece of very fine copper wire (No. 36 or 40) across the gap between the two wires. Does it become hot? Finally use a fine iron wire (No. 36 or 40) to close the gap. Be sure to use the forceps. If you do not succeed well with one dry cell, use two or three connected **in series,** that is, with the zinc binding post of one connected with the carbon of the next (see § 178).

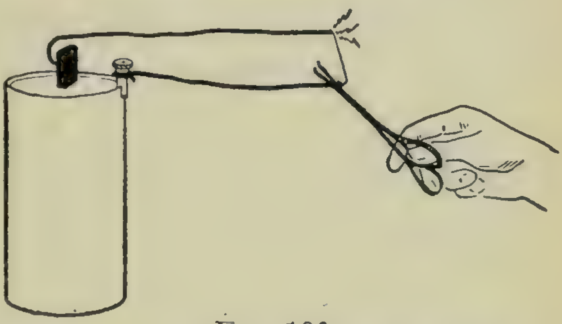


FIG. 180.
The current meets with so much resistance in the fine wire that the wire becomes hot.

The iron wire has more resistance than a copper wire of the same diameter, and the resistance of the fine copper wire is greater than that of the larger one.

Is energy of motion readily turned into heat? Review §§ 50 and 115.

190. How Electricity Produces Light.— The first successful **incandescent bulb** lights were made by Thomas Edison in 1879. What does "incandescent" mean?

We know that if the temperature of a body is sufficiently high, it gives off **light** as well as heat. What is the difference between a hot coal and a red-hot one? We also know that if the wires carrying a current are of materials having the right **resistance** and of sufficiently small diameter, we can turn the current into heat. In the electric bulb we get both heat and light. Edison's incandescent bulbs have fine wires, or *filaments*, of charcoal. The hot charcoal does not take fire, and burn, because the bulb does not contain air. The charcoal is being heated in a *vacuum*. The intense heat does, however, change some of the carbon into vapor, and this is deposited on the inside of the bulb and darkens it.

Mazda lamps (Fig. 181), as we have seen, contain filaments, not of carbon, but of *tungsten*. The filaments are of very small diameter: about 0.03 of an inch. The chief objection to carbon lamps is that they turn so much of the current into heat. Tungsten lamps give about **3** times as much light, for the same amount of electricity, as carbon lamps do. Some modern, very bright bulbs are filled with **nitrogen**.

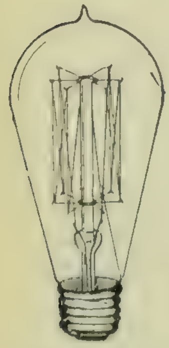


FIG. 181. The incandescent bulb contains a fine tungsten wire that can be heated to white heat by the electric current.

Arc lights are the large electric lamps used for street lighting and for stereopticons. They give a bluish-white light. They consists of two carbon rods placed a little distance apart: perhaps $\frac{1}{4}$ of an inch. The resistance which the current meets at this gap produces a very high temperature: about 3,800° C., and turns some of the carbon into vapor. The current crosses the gap through this **arc** of carbon vapor, heating it to intense brightness. If the rods are exposed to air, they must be renewed from time to time, as their tips are gradually burned away.

191. Protecting the House from Electricity.— We have learned the effect of passing the electric current through a very fine wire (see § 189); but because copper wires are expensive, they are usually made of as small a diameter as possible. There is danger in this, because the wires may be compelled to carry a much greater current than they are intended to, and may be **overloaded.** It is one thing to compel a fine copper wire to carry the current from a simple cell, and a quite different thing to load it with the current of an electric lighting circuit. If a wire is greatly overloaded, the increased resistance produces **hot** wires. Again, if two wires are too close together and not properly insulated, sparks may pass between them. Thus "crossed wires" and "short circuiting" (§ 182) are frequent causes of fires.

The laws compel builders to insulate carefully the wires that bring heating and lighting circuits into our houses. When such wires pass through wood, they must be insulated by means of tubes of porcelain or some other nonconducting materials. In a modern building the wires are not only carefully insulated, but the insulated wires are themselves carried in **metal** tubes, or **conduits** (kŏn′dĭts) throughout the building. Such tubes prevent the insulation from being worn off by handling, or eaten off by mice.

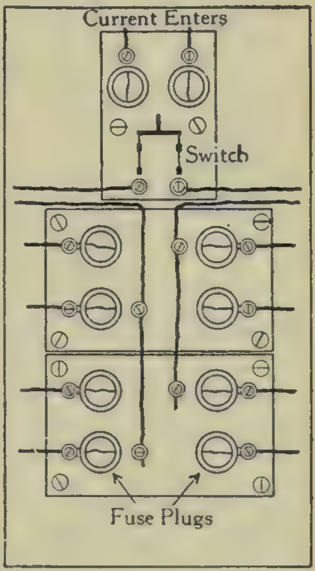


Fig. 182.
A fuse box consists of a set of fuse plugs, each containing a short piece of an easily melted metal wire. Before the copper wires on any circuit become hot enough to cause a fire, the fuse wire melts, and breaks the circuit.

What is a "live" wire? Why is it dangerous for such a wire to come in contact with wood or paper? Why is it dangerous for a person to handle?

To avoid the rise of temperature in a circuit to the danger point, the electrician places a **fuse box** (Fig. 182) in the house. To "fuse" means to *melt*. The box is made of metal or lined with asbestos; why? The **switch** through which the current from the outside, "service line," enters the house, is usually in the same box. There is a **fuse,** or wire made of a low-melting alloy, through which the current of each circuit must pass. If for some reason the amount of current in a circuit becomes too great, the fuse melts and breaks that circuit, and so prevents a possible fire.

Find the fuse box and switch in your house and examine them carefully. Also examine a **fuse plug.** When you open the switch, you cut off the current from the house. You ought always to do this when any work is being done upon the electric system of the house.

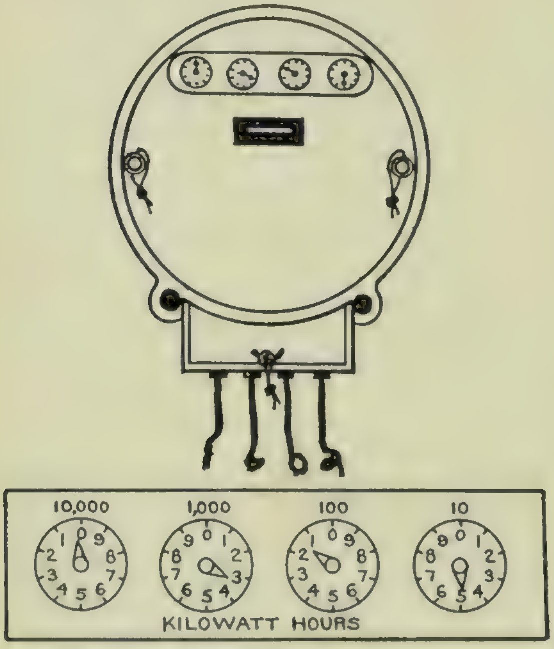


FIG. 183.
The electric meter is a delicate motor which is used to measure the amount of current consumed.

192. How to Measure Electricity.—The electric light and power company installs a **meter** to measure the amount of current each house or apartment uses, and reads the meter about once a month. Electric power is measured in **watt-hours** or **kilowatt-hours.** A kilowatt is 1000 watts, as a kilogram is 1000 grams (see Appendix I). A kilowatt is equal to 1.34 **horse-powers** (see § 116). A kilowatt-hour is an electric power of one kilowatt working for one hour.

The **electric meter** (Fig. 183) is a metal box having on its face several dials, each with a hand, or pointer, as in the water meter, Fig. 73, § 95. The dial on the right measures **up to** 10 kilowatt-hours; the next one to 100, and the one on the extreme left to 10,000.

Write down the readings of the meter shown in the figure.

The electric watt-hour meter is really a tiny, finely built **motor** (see § 187). The "field" of its electromagnets is produced by the current to be measured, and exerts force on the "armature," causing it to revolve. The armature is delicately mounted on steel balls and jewels. As the armature revolves, it sets gear-wheels in motion, and these in turn move the hands of the dials.

193. Summary.— **Natural magnets** are **lodestones.** When free to move, magnets assume a preferred position, which is, with us, about **north and south.**

When a magnet is **broken in two,** each piece is a magnet.

The **law of magnets** is that like poles repel one another, while opposite poles attract one another.

Magnets are **permanent,** or **temporary.**

Magnetic substances can be magnetized by **contact,** or by **induction.**

A **magnet** has a "field" surrounding it.

The **earth** is a magnet, with **magnetic poles.**

Objects of different materials, when **insulated,** and **rubbed** together, produce **electric charges.**

Insulators are **nonconductors.**

The **law** of charged bodies is that two like charges repel each other, while opposite charges attract.

Induction is the influence of a charged or magnetized body upon another body, by nearness, without contact.

An **electric condenser** consists of two conductors separated by a **dielectric.**

Lightning is an electric spark.

A **simple voltaic cell** consists of two different metals in a dilute acid, with connecting wires.

An ordinary **dry cell** consists of a zinc box containing a carbon stick surrounded by a **paste** of sal ammoniac, water, and other materials.

Cells may be **connected** "in parallel" or "in series."

In **storage batteries** we store **chemical energy** which we can get back as an **electric current.**

We **electroplate** an object with copper by the **electrolysis** of a copper sulphate solution.

A **wire carrying a current** is a **magnet.**

An **electromagnet** has a **coil** and a **core.**

The electric **doorbell** and **telegraph** are **electromagnets** in which the circuit can be made or broken at will.

The **magneto** and **dynamo** are machines in which coils moved rapidly through magnetic fields produce currents.

The **motor** is a machine in which a coil placed in a magnetic field is set in motion by a current.

Electricity brings into our houses **power, heat, light,** and **communication at a distance.**

Electricity produces **heat** and **light** because of the **difference in resistance** between the service wire and the conductor of the heating or lighting unit.

Houses are protected from electric currents by **insulators** and by **fuses.**

The **electric meter** is really a delicate **motor.**

194. Exercises.— 1. Why is copper used for trolley and lighting wires, and iron for telegraph wires?

2. Write in the Morse Code: "Buy 1000 barrels of flour market price." Leave short spaces between letters and longer ones between words.

3. What is meant by the terms "double plate," "triple plate," and "quadruple plate," as applied to silver articles?

4. How could a slab of impure copper be purified by the electric current?

5. Give the uses and advantages of electromagnets.

6. What is the use of the telegraph in railroading? In the Weather Service? In business? In the making of newspapers?

7. How could coal be converted into energy at the mine and the energy transported without the shipping of the coal?

8. How may the power of the wind be used to light an electric lamp?

9. What changes of energy are necessary in order that a waterfall of the Feather River may run a vacuum sweeper in San Francisco?

10. If a piece of steel is held near a dynamo, it is pulled strongly toward the dynamo. If held there a while, it becomes a magnet. Tell why.

11. Why are glass or porcelain protectors used on telephone poles?

12. When you disconnect an electric flat-iron, a light on the same circuit usually burns more brightly. Why?

13. Name all the uses of electric motors.

14. How can you light an electric lamp by pushing a button?

15. Why should we not touch a bare wire of the lighting circuit if we are near metal fixtures or water pipes?

16. If your electric doorbell will not ring, where will you look for the trouble? Where, if it will not stop ringing?

17. Why does ice on a trolley wire cause the pole of a passing car to produce sparks?

18. Name all the ways in which electricity brings "communication at a distance" into our houses. See Summary.

19. A quantity of copper rivets and iron tacks are mixed together; suggest an easy way of separating them.

195. Projects.—1. From a dealer in Ford car parts get a magnet of a discarded magneto and show the class how to determine which is its N-seeking pole. Suggestion: Use a compass needle; also note whether it is by attraction, or repulsion, that we test the presence and kind of a magnetic pole.

2. Collect specimens of sand from several sources, such as the seashore, the shore of a lake or stream, and from a dealer in building materials, and determine if any of them contains a magnetic substance.

3. Have a blacksmith cut a pair of suitable steel bars for you; then have the engineer of a dynamo magnetize them. Report the operations and show the magnets to the class.

4. Make a dipping needle and show the class how it works.

5. Make two floating compasses out of sewing needles, and show their behavior toward each other.

6. Test for magnetism various pieces of steel that have been lying around a plumber's or a blacksmith's shop.

7. Test a steel rod, such as a poker, for magnetism. If it is not magnetized, hold it toward the earth's north magnetic pole, and

strike it several times with a hammer or mallet. Report your results.

8. Prepare a paper on methods used in steering a ship at sea, including "dead reckoning."

9. Make a map of the "field" of a **U**-magnet as in § 169, and show the results to the class.

10. Make a map of the field of a bar magnet on blue-print paper. Cover the magnet with a piece of fresh blue-print paper, sift iron filings from a small cheese-cloth bag upon the paper, and tap the paper so that the filings may arrange themselves in the lines of force. Then expose the paper and filings to light. Afterward wash the paper thoroughly with running water, and dry it. Show result to class.

11. Make a map, on blue-print paper, of the fields of two bar magnets with their **like** poles placed, say, an inch apart.

12. Make, on blue-print paper, a map of the fields of two bar magnets with their **opposite** poles about an inch apart.

13. Magnetize a knife blade so that the tip shall be **N**-seeking, and demonstrate the operation and result to the class. Magnetize another so that the tip shall be **S**-seeking. Always draw the blade **in one direction** over the proper pole of the magnet used for the magnetizing; not back and forth.

14. Charge your body by friction as in § 177, Ex. 2; then test the effect of it by bringing your finger near an electric pendulum and a wooden ruler suspended by a silk thread.

15. Make electric pendulums out of the pith of dry burdock and cornstalks; also out of bits of cork and wads of paper.

16. Electrify a glass rod by rubbing it with silk. Then prove to the class that the silk has a **negative** (−) charge.

17. Electrify a smooth, wooden ruler, held in your hand by means of a dry woolen mitten, by rubbing the ruler with another mitten. Determine the kind of charge on the ruler.

18. Electrify a brass rod, held in a nonconductor such as a rubber glove or silk pad, by rubbing it with silk or wool, and prove to the class the kind of charge on the rod.

19. Determine the declination of the compass for the place in which you live.

20. Prepare an empty egg shell, cover it with tin foil, and suspend it. Then electrify it with a negative charge, first, by contact, then by induction. Prove results to class.

21. Demonstrate to the class the construction of the condenser of a radio set, or of a Leyden jar.

22. Make a simple voltaic cell, as in § 178, and demonstrate it to the class.

23. Make a simple cell from iron and copper and prove that a current flows. Make another from zinc and carbon. Use for the carbon the discarded "pencil" of an arc light. Show both cells to the class.

24. Set up for the class a liquid sal-ammoniac cell, either a commercial form or a home-made one, and show how it works.

25. Take apart a discarded "dry" cell, and show its construction to the class.

26. Show how to connect two cells "in parallel" and "in series."

27. Demonstrate to the class the construction of an automobile or radio storage battery.

28. Show the electroplating of an iron spoon with copper (see § 180).

29. Magnetize a steel knitting needle by placing it in a coil of insulated wire and passing a current through the wire.

30. Make an electromagnet from a coil of insulated wire and a core of soft iron. Demonstrate its working as you make and break the circuit.

31. Demonstrate the construction of a doorbell to the class.

32. Set up a doorbell in series with a dry cell and a push button, and show its operation to the class.

33. Set up a telegraph key-and-sounder instrument, and show its working to the class.

34. Construct a miniature electric crane.

35. Find out how a fire alarm works and report upon it to the class.

36. Prepare a report upon the way in which the idea of the telegraph came to Morse and his efforts to get the invention into use.

37. With a coil and a permanent magnet demonstrate the formation of a current (§ 185).

38. Demonstrate the parts and the operation of the magneto of a Ford car.

39. Prepare a paper upon the way in which a dynamo, or generator, is constructed, and the different types of generators.

40. Demonstrate the working of a small generator, such as that in an automobile, to the class.

41. Prepare a paper on the effect of water power in the development of the American Colonies.

42. Write a paper on water power and coal as sources of electricity in this country.

43. Write a paper on the industries using the current developed at Niagara Falls.

44. Demonstrate the construction and operation of a toy motor, and use the motor to produce motion in some toy machine.

45. Demonstrate the working of a vacuum cleaner.

46. Prepare a paper on the different kinds of electric washers, their operation, and the advantages of each.

47. Demonstrate the working of an electric iron, coffee percolator, and toaster.

48. Collect samples of different kinds of electric-light bulbs and tell the class about them.

49. Show the class different forms of fuses, such as those used in automobile generators and in lighting circuits. Show also a knife switch.

50. Make a collection of different insulators used for electric wires and instruments, and report upon them in class.

51. Show the operation and reading of an electric meter.

52. Prepare a report on the life and work of Faraday.

196. References.— ADAMS: *Harper's Electricity Book for Boys.* ALLEN: *Mechanical Devices for the Home.* Books on Inventions and Inventors (see § 6). FISHER: *The True Benjamin Franklin.* LANCASTER: *Electric Cooking, Heating, and Cleaning.* MEADOWCROFT: *A-B-C of Electricity.* MILLIKAN AND GALE: *A First Course in Physics.* SLOANE: *Electric Toy Making for Amateurs.* THOMPSON: *Michael Faraday, His Life and Work.* TOWER, SMITH, TURTON, AND COPE: *Physics.*

CHAPTER XII

HOW WE USE LIGHT

197. Light in the House.— The original purpose of a house was to provide **shelter** from the weather and from human and animal enemies. Hence the openings of the house were few, and made so that they could be closed quickly. The **castle,** with its thick walls, and its narrow slits to serve as windows, illustrates this fact admirably. To get sunlight, early men, and our own ancestors of a few generations ago, had to go out of doors.

Even when men could live with less fear of one another and of wild beasts, the problem of the window was still a serious one; for there was no suitable material for closing the hole in the wall and at the same time letting sunlight in. Oiled paper, isinglass (the mineral **mica**), and thin sheets of horn have been used. They are still used in some communities. But none are so good as glass. It is so important for us to have sunlight in the house, both for sight and for health, that the men who gave us cheap **glass** must be put among the greatest benefactors of our race. Darkness in the house means **dirty** surroundings, and where these exist disease is sure to follow. When early man shut out his *larger* enemies by living in a cave or a house, he shut in **smaller,** but equally powerful enemies without knowing it. These are the **germs** of disease, which are almost sure to flourish in the house that has no sunlight.

Glass.— Glass is made out of sand, limestone, and soda. The mixture is melted in fire-clay pots about 4 feet high and 4 feet in diameter, until a clear, transparent liquid is obtained. When this has cooled, it forms a **pasty** mass before hardening. In this condition vessels and other objects can be made from it, and it can be "blown" into many shapes (Figs. 184 and 185).

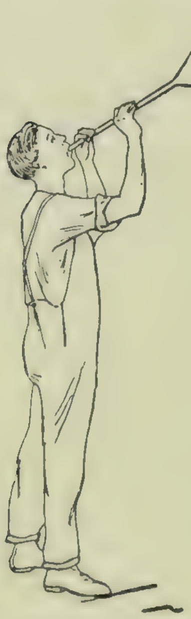


FIG. 184.
The glass blower blows a lump of hot, soft glass into a hollow globe. When this is cut open, and softened by heat, it forms a flat sheet.

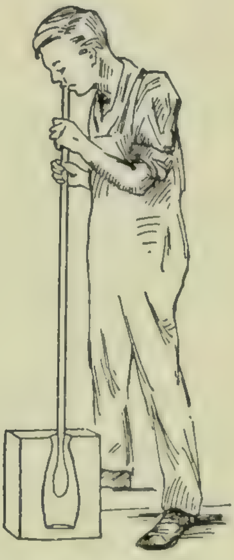


FIG. 185.
The workman, or a current of compressed air, blows into the lump of hot, soft glass attached to the hollow tube, until the glass takes the shape of the mold.

By the older process, men made **window glass** by cutting a cylinder of glass open lengthwise, so that it formed a sheet. In the newer process, a great deal of glass is melted at one time in a tank, and a machine draws it out into sheets of any desired width and thickness. **Plate glass** results when melted glass is poured out upon hot iron plates; it is flattened by means of heated rollers.

198. Lighting Houses at Night.— Instead of giving up their work or pleasure with the coming of night, men have for ages tried to lengthen the day by means of artificial lights. The pioneers of this country used the open fire for light by which they worked and read, as well as for heat to keep them warm. The early lamps (Fig. 186) were metal vessels containing grease or oil. Lard, olive, and whale (sperm) oils were used. The oils burn with a smoky flame; but by the use of **wicks** they are drawn up, a little at a time, and changed into vapor. It is the vapor that burns (see § 26). The oils have a very high boiling point; hence the body of oil is not readily set on fire. The Eskimos still use such lamps, with flames sometimes two feet high (see § 37).

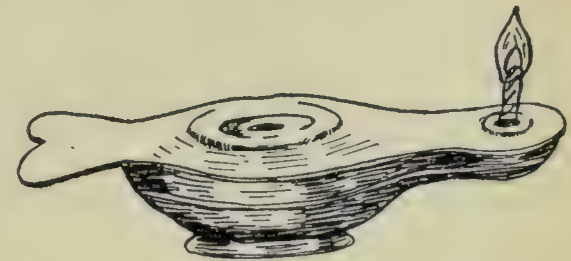


FIG. 186.
A lamp of Roman times, in which lard or olive oil was burned to give light.

Candles were an improvement upon the early oil lamps. They were not nearly so heavy, and they could be moved without being spilled. Candle-making was originally one of the regular household duties. The wick was dipped into the melted fat or wax, allowed to cool, and then dipped again, until it had the desired thickness.

In modern candle-making the wick is set into a mold, and the melted wax is poured around it. Hundreds of candles are thus made at one time. Formerly "snuffers" were needed to cut off the charred wick inside the flame. Snuffers are no longer needed; for the reason that one of the threads of the wick is now pulled more tightly than the others; as a result the tip of the wick curves outward to the edge of the flame, where the air oxidizes it (see § 25).

Kerosene lamps, which first came into use about 1860, were a return from the solid candle to the liquid-fuel lamp. **Petroleum** had just been found (1859) in Pennsylvania, and this discovery gave the world a new source of heat, light, and power; for by the distillation of petroleum combustible liquids, such as gasoline and kerosene, are obtained. Gasoline has so low a boiling temperature, and changes so readily to vapor, that it is not used for lighting purposes as a liquid, but as a gas. Kerosene has a much higher boiling point than gasoline and can be burned with a wick, as the oils can. But it cannot be burned with a wick **alone,** because it smokes badly. To increase the air supply, and so to prevent smoking, kerosene lamps have **chimneys** supported by **burners.** The heated air and gases carried upward by convection create a **draft,** by which fresh portions of air are brought to the flame. **Central-draft** burners (Fig. 22, *b*, § 25), with circular wicks, give a more intense light than flat-wick burners, because they allow more kerosene to burn in a given time. Air is drawn to the **inside** of the flame as well as to the outside.

199. The Candle Power of a Lamp.— We know that, of two objects, the one nearer the source of light receives the greater **amount** of light. If one person is twice as far from a reading lamp as another, he receives not $\frac{1}{2}$ as much light, but only $\frac{1}{4}$ as much. A third person, sitting 3 times as far away as the first, gets only $\frac{1}{9}$ as much light.

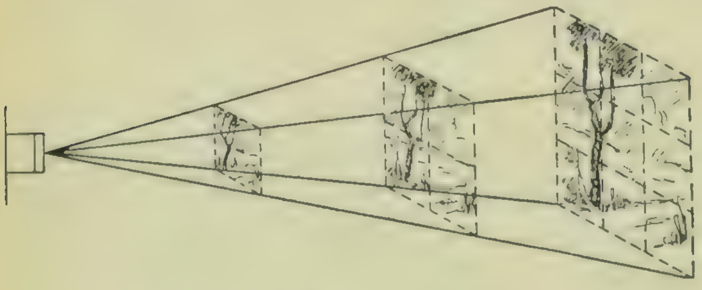


FIG. 187.
At twice the distance from the light the picture is 4 times as large, but only ¼ as bright. At 3 times the distance it is 9 times as large, but only 1/9 as bright.

Study Fig. 187. The source of light should be very small, so that the light shall come from practically **one point** (see § 155) and cast **distinct** shadows. If a card 1 inch on a side (its area is 1 **square** inch) is placed, say 3 inches from the light, its shadow will exactly cover the second card, which has 4 times the area, and is twice as far away. Its shadow will also exactly cover the third card, which has 9 times the area and is 3 times as far away.

The **standard** for the *intensity*, or brightness, of light is the **candle power.** The **standard candle** is of sperm fat, weighs $\frac{1}{6}$ of a pound and burns at the rate of 120 grains (7.78 grams) an hour.

We get the candle power of a lamp by using a **photometer** (Fig. 188). This is a piece of oiled paper supported in a frame, and a pencil that can be set upright near the paper. The room must be dark, except for the lamp and candle to be compared. These two are lighted, and placed so that the two shadows of the pencil fall on the oiled screen side by side. The distance of the lamp or candle is then altered, so that the shadows are equally dark. Suppose that the distance between the candle and its shadow is 1 foot, and that between the lamp and its shadow, 4 feet. We *square* each of these numbers; that is, we *multiply each by itself.* The square of 1 is **1**, and that of 4 is **16.** So the lamp has an illuminating power 16 times as great as that of the candle. We say it is a **16 candle-power** lamp.

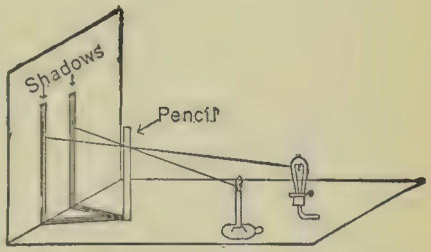


FIG. 188.
How to get the "candle power" of an electric light.

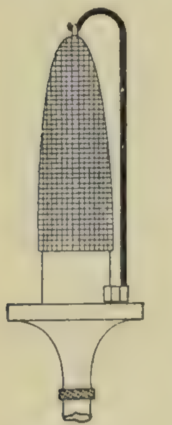


FIG. 189.
In the mantle light a Bunsen flame heats a film consisting of oxides of certain rare metals. These become white hot and give off a brilliant light.

200. Gas for Lighting.— The adopting of gas and electricity as sources of heat and light produced a decided change in American life. Up to that time each household provided its own light and fuel independently. But gas and electricity are produced most economically on a **large** scale; hence the business of generating and distributing them was entrusted to **public service** companies, and the community depends upon these companies to supply its needs.

We have already studied the production of electricity for common use (see § 188). The **gas** brought to our houses is one of several kinds:

(1) **Natural gas,** which is found in the earth in some places and is distributed to houses, either by itself or mixed with artificial gas;

(2) **Coal gas,** made by the heating of soft coal in closed vessels;

(3) **Water gas,** made by the passing of steam through beds of hot anthracite coal or coke.

The gas used in most cities is water gas mixed with gases obtained by the charring of petroleum (see § 59); the mixture gives more light in burning than water gas alone. However, people now demand a much brighter light than that given even by "enriched" water gas; hence gas used for illumination is usually burned in a **mantle** burner (Fig. 189). This is really a **Bunsen burner** (see § 40), and in its hot, colorless flame the solid mantle, or covering, is heated to **white heat** (incandescence).

The best mantles contain compounds of two rare metals: **cerium** and **thorium.** The mantle is first knitted out of "stockinet." It is then soaked in a solution of the compounds of the two metals named. When the stockinet is dried, the solid compounds fill its pores. When we set the mantle on fire, the stockinet burns up, and the **oxides** (see § 29) of the metals remain as a thin, fragile shell. Other gases, such as natural gas and gasoline vapor, are used with incandescent mantles.

Gas is **stored** by the gas company in large, floating tanks set, upside down, in water. They rise when they are filled with gas, and sink as the gas is used up. They are loaded with weights which, with the weight of the tanks themselves, cause the **pressure** of the gas. The pipes ("mains") that carry the gas away from the tanks are of iron; sometimes they are 3 or 4 feet in diameter.

Lighting and fuel gases usually contain a great deal of the poisonous gas, **carbon monoxide** (see § 75). Leaks in gas fixtures and stoves should be mended immediately.

Acetylene is a gas, made, for household and commercial use, in a generator in which lumps of **calcium carbide** are dropped into water. It must be burned in a special burner.

201. The Gas Meter.— In most houses the gas meter is found in the basement. It is a metal box (Fig. 190) with dials much like those of water meters and electric meters (see §§ 100 and 192). It consists of two compartments the size of which is regulated by two movable diaphragms. The diaphragms are forced inward and outward by the gas pressure. A "slide valve" (see Fig. 260, § 273) changes the path which the gas must take, so that the compartments may be filled and then emptied. As the diaphragms move back and forth, they move the hands of the dials. Since the capacity of the compartments is known, and since the dials show how many times the compartment has been filled and emptied, the dials also show how many cubic feet of gas pass through the meter.

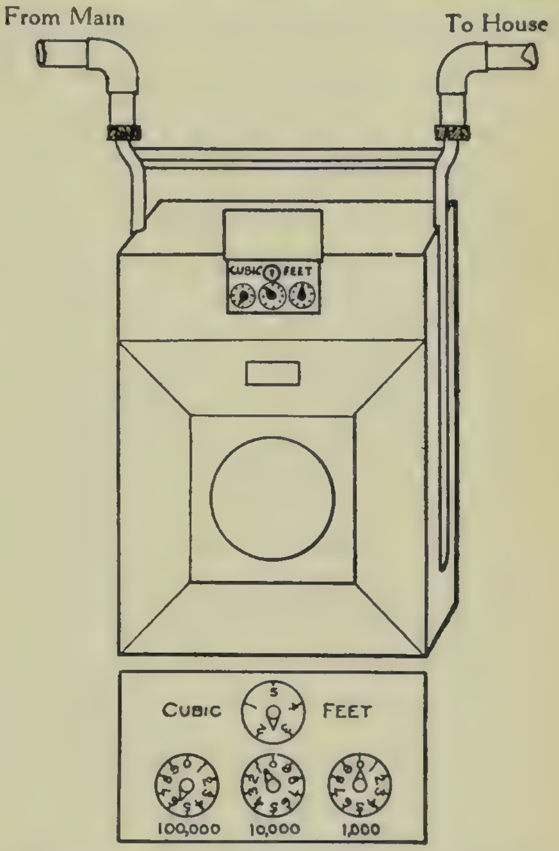


Fig. 190.
Gas meter, with the dials, magnified, below it.

202. Why We See Objects.— We *see* an object: (1) because it gives off rays of light; (2) because we have *eyes* which are affected by light. Our greatest light-producer, the **sun** (see § 152), generates its own light; or is **self-luminous.** The same is true of a burning candle, an electric-light bulb, and a firefly. Most of the bodies that we see are not self-luminous, but **reflect** light from some luminous body. Such are the moon, a tree, and a cloud. An object which we see by moonlight is really seen by sunlight that has been reflected **twice**: first from the moon to the object, and then from the object to our eyes. When we light an electric bulb in a dark room, the objects in the room become visible because they reflect the light of the bulb to our eyes. What is the source of the light by which we see the North Star? The planet Mars? A flash of lightning?

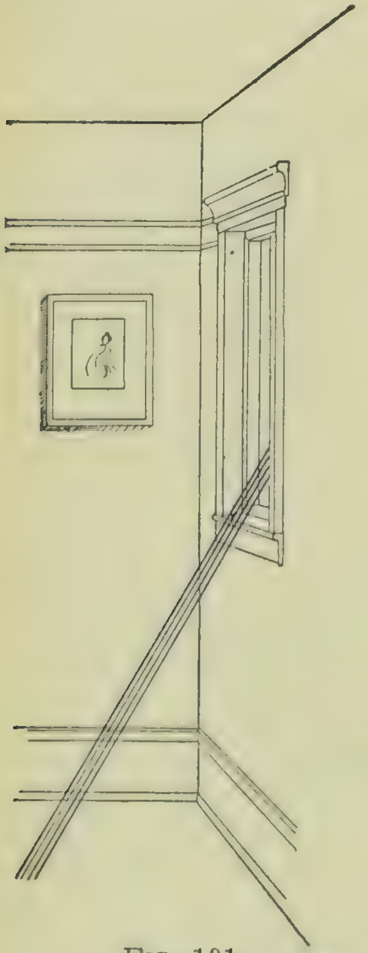


Fig. 191.
The straight path of the sunbeam is made visible by the dust particles that reflect its light to our eyes.

Bodies through which we can see clearly are **transparent**. Such are glass, water, and air. A body through which light does not pass is **opaque**. Name several opaque bodies. Some materials allow some light to pass, but not enough for distinct vision; we call them **translucent**. Oiled paper, fog, thin china, and horn are examples. **Ground glass** is translucent because its surface is so rough (see § 11) that it scatters, or **diffuses**, light in all directions. Why is the foaming top of a wave **white**?

203. What Light is Like.— If a sunbeam comes into a dark room through a small opening, we see that it travels in a **straight line** (Fig. 191). On a foggy night a street lamp sends out straight beams of light. We call a single line of light, a **ray**, and a number of parallel rays, a **beam**. Does the formation of **shadows** prove anything regarding the direction in which light rays travel (see § 155)?

When we think of it, we realize that if it were not for bodies that turn the sun's rays from their straight course, we could see sunlight only when we are looking **directly** at the sun. The objects around us: trees, grass, water, houses, stones, clouds, the dust and water particles of the air, all these **reflect** sunlight to us, and we do not need to look at the sun in order to get its light. **Daylight** is thus *scattered*, or diffused, sunlight.

We have already learned of the enormous velocity of light (see § 152): about 186,000 miles a second. Scientists have found that light comes to us in **light waves,** through space. **Sound** travels through **air** at the rate of about 1100 feet a second; very slowly as compared with light. Why do we see the flash of a gun before we hear the report? Why do we see the lightning before we hear the thunder?

Sunlight brings us other forms of energy besides light. It brings **heat.** It also contains **chemical energy.** Thus, it **tans** our skin, takes a **photograph,** and helps **green plants** prepare material for their food and growth out of water and carbon dioxide (see § 65). The other forms of energy in sunlight are all turned into heat when absorbed by some object. Direct sunlight, not filtered through glass, has actually been found to assist in the cure of certain diseases.

204. How a Mirror Affects Light.— A mirror is a sheet of glass covered on one side with a thin layer of some metal, usually *silver*. Ancient mirrors consisted of the highly polished metals themselves. If you hold a mirror in the path of a sunbeam that is coming into a room, you can direct the beam out of the room by the path by which it entered, or you can direct it to the other side of the room or to the ceiling. The mirror will **reflect** the sunbeam in either case, but the path of the reflected light will depend upon the slant, or **angle,** at which you hold the mirror.

If you throw a tennis ball vertically down on a smooth, horizontal sidewalk, it bounds up in the same direction. But if you throw it down at an angle, it bounds off at the **same angle,** but in the **opposite direction** (Fig. 192). Light bounds off, or is **reflected,** in the same way; the angle at which a beam of light is reflected from a mirror has the same size as the angle at which it strikes the mirror. If you stand at one side of a mirror and see in the mirror the image of another person, you may be sure that he can also see your image.

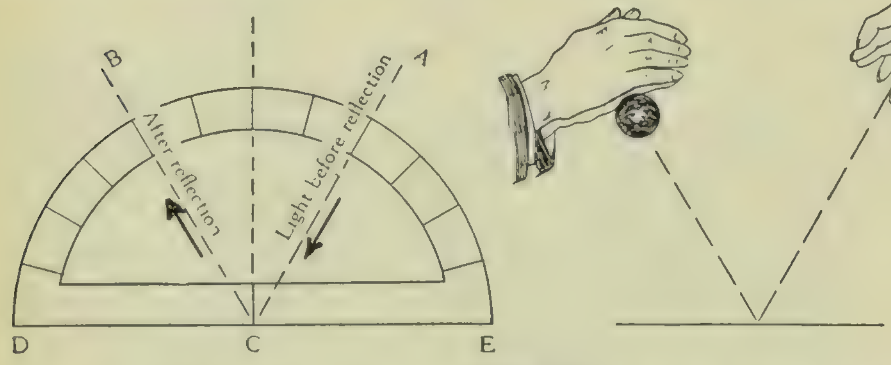


FIG. 192.

If you throw a tennis ball to the sidewalk at an angle, it bounds off at the same angle, but in an opposite direction. A beam of light is reflected by a mirror in the same way.

One other fact must be taken into account in the study of mirror images: the eye always reports to the brain that it **sees** an object in the direction from which the light comes to itself (Fig. 193). Hence a watch held in front of a mirror seems to be as far behind it as it actually is in front of it. The light rays go from the watch to the mirror, and from the mirror to the eye, in straight lines, but their direction is changed at the mirror.

Because of the reflection of light and the behavior of our eyes we "see" many phenomena that are deceptive, and we need our **judgment** to correct the evidence of our sight. Thus the **right** side of an object becomes the **left** side of the image in a mirror. If you hold an open book before a mirror, the letters seem to be printed backward. A watch showing 10 A.M. seems to show 2 P.M. Try this.

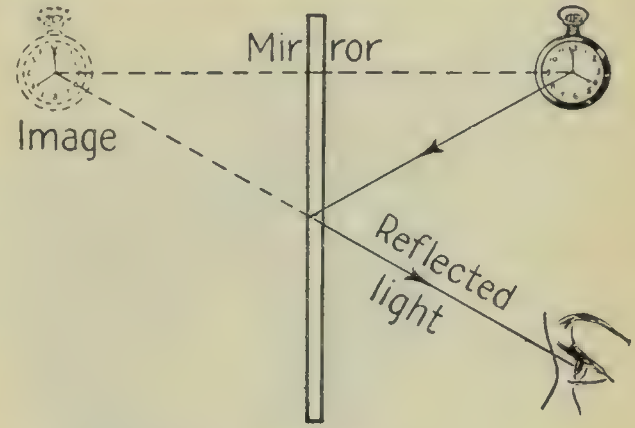


FIG. 193.
The watch seems to be behind the mirror, in the direction from which the reflected light rays enter the eye. Is the image different from the watch?

A startling trick due to reflection is that shown in Fig. 194. Try it for yourself. If you look at a piece of polished plate glass at the correct angle, it is a mirror, and yet is transparent at the same time. If you place a bottle of water behind the glass, and a burning candle in front of it, you can see both objects in the direction from which their light comes to your eyes. Hence they both appear to be at the same place, behind the glass, and the candle *seems to be burning in the water.*

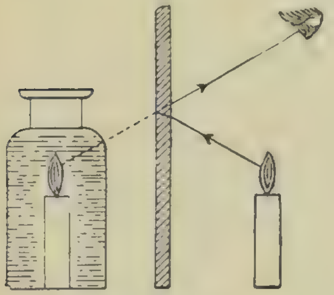


FIG. 194.
The thick glass plate acts both as a reflector and as a transmitter of light. The candle seems to be burning in the water.

The **periscope** is another interesting application of the reflection of light (Fig. 195). By means of it the "lookout" of a submerged submarine can see what is happening above water, and a soldier in the trenches can see as if he were above ground. We can use it for seeing "around a corner" anywhere, as on a railroad curve. How might a mirror, placed in an inclined position beside a railway track, help prevent crossing accidents?

205. How a Transparent Body Affects Light.— Light is bent from its straight course not only by mirrors, which reflect it, but by transparent bodies, through which it passes. If you lay a piece of plate glass across part of a straight mark (Fig. 196), and look through the glass **obliquely,** the line seems to be **broken** at the edge of the glass. What happens is that the light from the mark is **bent** by the glass, and we see that part of the line out of its true position.

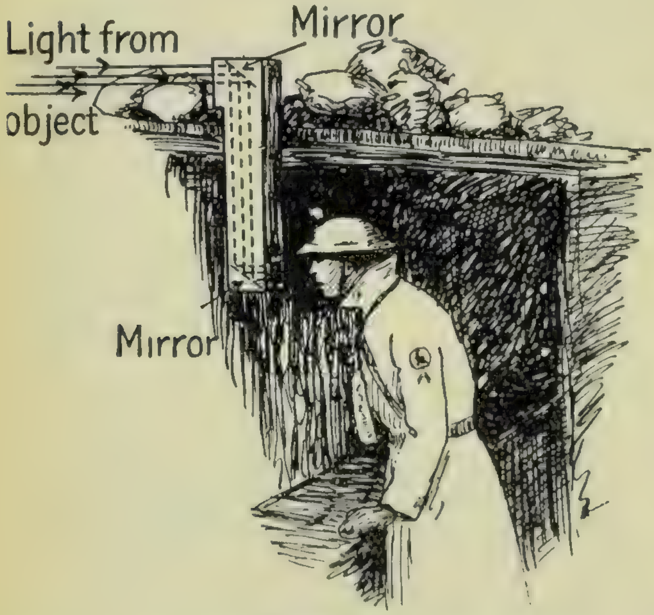


Fig. 195.
How a periscope, with its mirrors in an enclosed box, enables us to see around corners.

Fig. 197 illustrates what happens when light passes from water into air. Carry out this **experiment**:—Place a coin in the bottom of a cup, and raise the cup so that the coin just disappears. Then pour water slowly into the cup, and note that the coin seems to **rise.**

Is a fish at the bottom of a pond just where it **seems** to be? Not if your **line of vision** is oblique to the water's surface; for the light is bent **toward you** as it leaves the water,

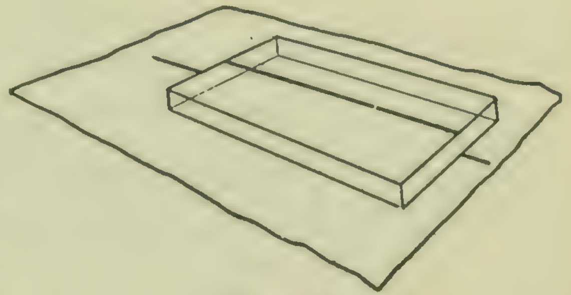


Fig. 196.
As the light rays pass obliquely from the glass into air, they are bent, and the part of the line under the glass seems farther away than it really is.

and the fish therefore seems farther away than it really is. The water will also seem more shallow than it really is.

We call this bending of light by transparent bodies **refraction** of light. Light that comes to us from heavenly bodies is also bent as it enters our atmosphere, and the bending increases as the light approaches the earth's surface; because the air becomes more and more **dense** (see § 16). As a result, a heavenly body is never where it seems to be, except when it is at the zenith.

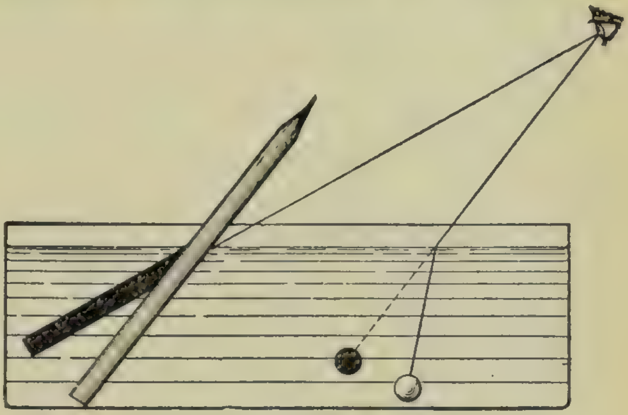


FIG. 197.

If you look obliquely at some object that is under water, the light rays which go to the eye are bent as they leave the water; hence your eye is deceived as to the true position of the object. Why does an oar or water plant sticking out of the water seem bent at the water's surface?

206. The Action of a Lens.

— We have already learned (§ 205) how a piece of plate glass bends rays of light as they pass from it into air. If the glass has a **curved** surface (a **lens**), its effect upon light is still more striking; for it is because of lenses that we have such important instruments as telescopes and microscopes, opera glasses and field glasses, projecting lanterns and eyeglasses, cameras, and many more besides.

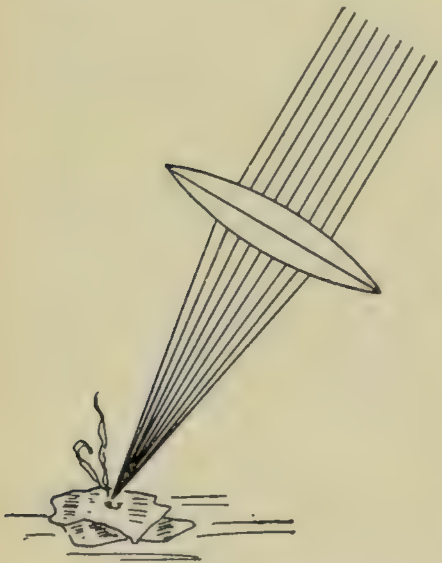


FIG. 198.

The lens bends the parallel rays coming from the sun and brings them together at one spot, or focus. There they can set paper or other inflammable materials on fire.

If you hold a reading glass or magnifying glass so that sunlight can pass through it (Fig. 198), you will find a position in which the glass brings the sun's rays together in a very small spot. The temperature at this spot may become so high that paper, a match, or other inflammable material, is set on fire. When a lens is used for such a purpose, we call it a **burning glass.** We call the point at which the light rays come together, the **focus** of the lens, from the Latin for "hearth." If the lens has very **convex,** or bulging, surfaces, its focus will be near the lens, if the surfaces are not so abruptly convex, the focus will be farther away.

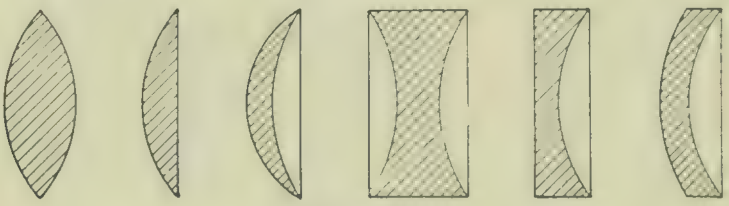


FIG. 199.

A set of six lenses of different forms. The form of each depends on whether its faces are: (1) convex (bulging); (2) concave (hollowed); (3) plane; or (4) A combination of two of these. The lenses that are thickest in the middle bring parallel rays together; those thickest at the edges spread the rays apart. Which forms could be used for a burning glass?

The figure shows that the light rays are bent toward the middle, **thicker** part of the lens. There is a **general rule** for all lenses (Fig. 199): lenses thickest at the middle bring light rays together; those thinnest at the middle spread them apart.

If you find the distance from a magnifying glass to its focus, and compare it with the distance at which you hold the object you wish to magnify, you will find that the object must be placed, not at the focus, but **between** the focus and the lens. Fig. 200 shows the path of the rays of light before and after passing through the lens. It also shows how, by the bending of the light rays, the eye is made to "see" the object as an enlarged image.

The **eye** has a lens, called the **crystalline lens,** set inside the front of the eyeball (Chap. XXII). This is a remarkable lens, for its curvature can be changed when we wish to look at objects at different distances. Unless the light is bent just the right amount, we cannot get a clear image of the object upon the sensitive film, called the **retina** (rĕt′ĭ-nä), placed at the back of the eye.

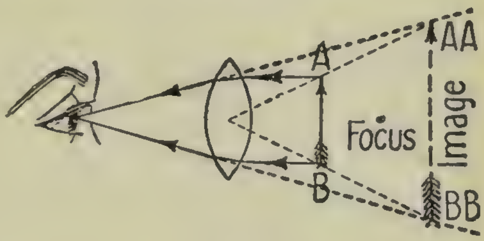


FIG. 200.
The magnifying glass makes the object placed between the focus and lens appear larger, but does not reverse it. Try placing the object beyond the focus, and alter the position of your eyes until you see a reversed image.

207. How a Camera Works.—A camera is a box in which the image of an object is allowed to fall upon a prepared *plate,* or **film,** and so "takes a picture" of the object. In order that the image may be formed properly, the light from the object is passed through a **lens.** But we can have a camera without a lens, in which the rays of light pass through a mere **pinhole.** A **card** with a pinhole in it, if placed between a bright object, such as a candle, and another card, will form an image on the second card. A **pinhole camera** (Fig. 201) works better.

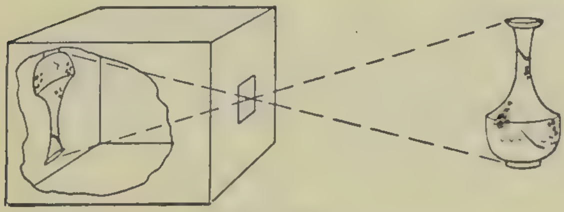


FIG. 201.
The image of the vase is formed inside the pinhole camera. It is reversed and upside down, because the lines of light cross at the pinhole. The vase must be illuminated brightly. A candle may be used instead.

The pinhole camera can be made out of a box with both ends removed. In the center of one side make a hole, cover the hole with tinfoil, and make a smooth pinhole in the foil. The inside of the box should be black, except for a white spot opposite the tinfoil, and the room should be dark. If you place an object, such as a vase, in the proper position in front of the pinhole, and **illuminate** it brightly, an **image** of the vase will appear on the white spot opposite the pinhole. If you put a lighted candle in this position, you will get an image of the candle. But both images will be **reversed** and **upside down.** The reason for this, as Fig. 201 shows, is that the rays from the object **cross** at the pinhole. If you direct the pinhole toward a landscape, you can get a miniature image of the landscape, also completely reversed.

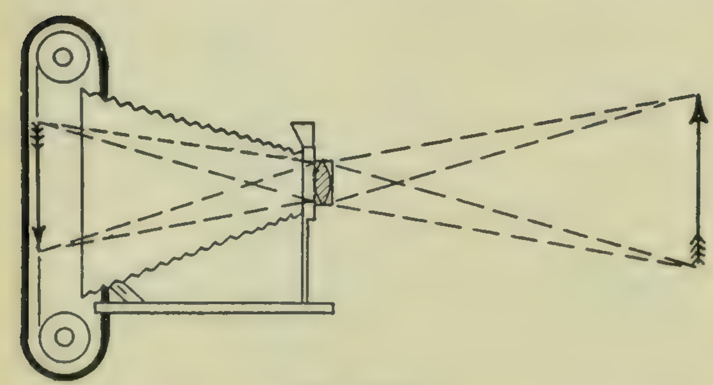


FIG. 202.
The camera's lens gathers some of the light rays reflected from each point of the object facing the camera, and brings each set to a focus on the film or plate.

In the **photographic camera** (Fig. 202) the **lens** gathers many more rays of light than can pass through the pinhole, hence there is a stronger, more definite image. Instead of a white spot, the camera has a *sensitive plate*, or film, on which the image can be made permanent. Usually it contains a compound of **silver.**

In "taking your picture" the photographer first brings your image to the proper **focus** upon a ground-glass screen at the back of the camera; he then puts the sensitive plate in place of the screen. When you are ready, he opens a **shutter** in the front of the camera, so that the active rays of light can be reflected from your body to the sensitive plate. Finally he closes the shutter, and stops the action of the light.

You cannot see an image upon the sensitive plate until it has been **developed.** Suppose that the photograph is that of a person with dark hair and a light-colored coat. The dark hair sends comparatively few rays to the plate; consequently the silver compound in this part of the image will be changed only a little. The light coat, however, reflects many rays to the plate, and the corresponding part of the image will have its silver compound changed much more. **Developing** is the process in which a solution of certain chemicals completes the process begun by the light, so that the **image appears** on the plate. A solution containing **pyrogallic acid** and **soda** is a common developer.

The next operation is called **fixing.** It consists in using a chemical called "hypo" to **remove** all of the **silver compound** that has not been changed. The plate is then washed thoroughly and dried. It is called the **negative.** Why? See Fig. 203.

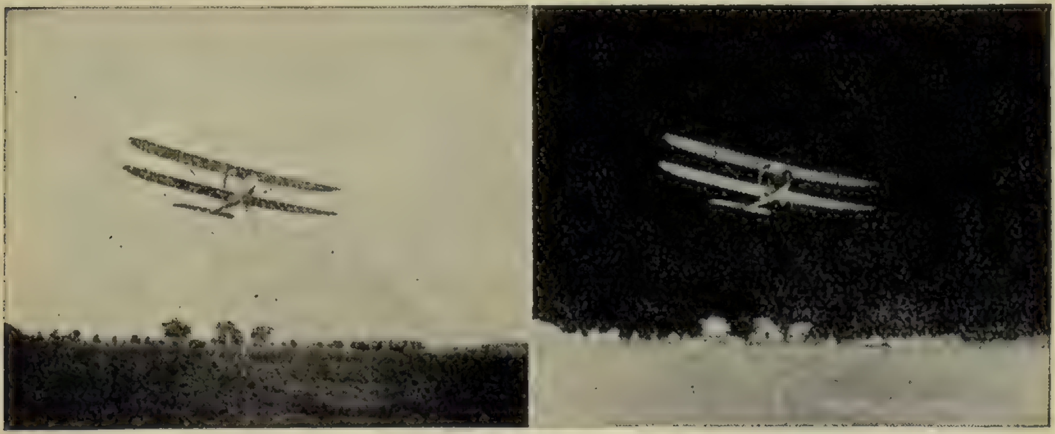


FIG. 203.

A positive and a negative photograph. The negative was formed in the camera. The positive was printed by light that passed through the negative.

The photographer makes the **positive** print, or photograph, by placing the negative over **sensitive paper,** also containing a silver compound, and letting light (often sunlight) shine through the negative. The light changes the silver compound on the paper most where there are light spots on the negative, and least where there are dark spots. Then, when the photographer **develops** and **fixes** the paper print, the picture has light spots where the negative was dark, and dark spots where the negative was light. Hence, in the **printed** picture, the light and dark spots are arranged just as they were in the person photographed.

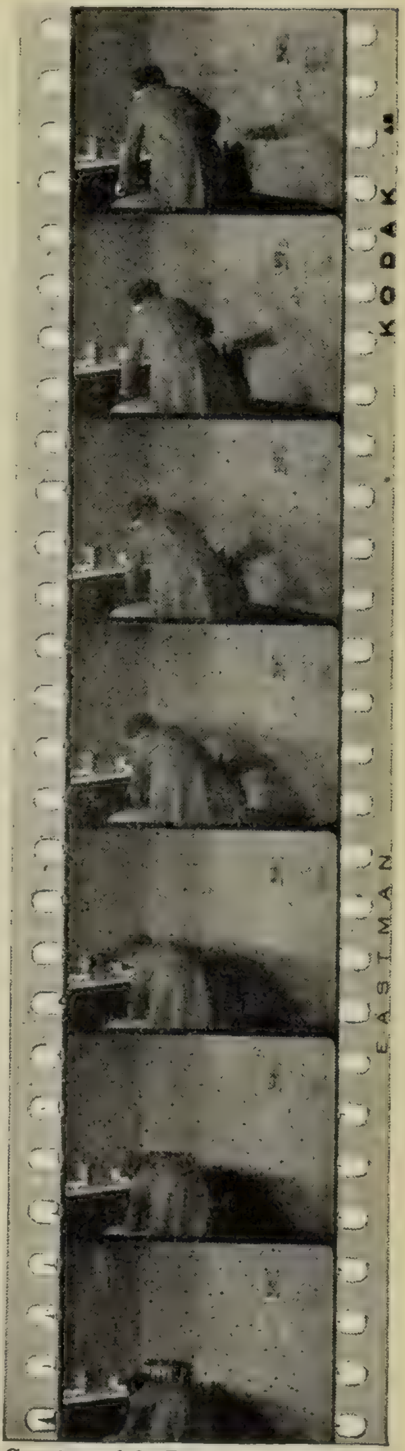
In the **kodak,** or similar camera, the principle is the same as in the photographer's camera. A **film** is used instead of a plate. Instead of looking for the image on a screen in the back of the camera, you use a "finder." This is a tiny box which reflects the image, so that you can see just how the image will appear on the film. There are adjustments to regulate the amount of light, the length of exposure to light, and the position of the lens for objects at different distances.

208. Motion Pictures.— When we see a motion picture, we usually think only of the enjoyment that it gives us. In order that we may have this enjoyment, a great deal of science has been brought into use. There must be not only actors and scenery, but at least two delicate and accurate **machines.** These are: (1) a motion-picture **camera,** by which the pictures are taken, together with its **film;** and (2) the **projector,** by which the images on the film are thrown upon the screen. In order to understand the motion picture we must also know something of the laws of the human **eye** and **brain,** and of the way in which our judgment interprets what the eye sees.

The **camera** for motion-picture taking is much like an ordinary camera, except that it is made to work with great accuracy and speed. In the ordinary camera we take one picture at a time, and then bring a new plate or film in the path of the light that has passed through the camera's lens. In the motion-picture camera we make a series of snapshot photographs, perhaps 16 to the second, on a continuous film, and each new portion of the film is moved into position by an automatic device. The camera-man has only to turn the crank.

The **film** (Fig. 204) used in the motion-picture camera is a transparent ribbon of celluloid or similar material, about $\frac{6}{1000}$ of an inch thick, including a thin coating which contains silver salts that are affected by light (see § 207). The celluloid ribbon is usually made $1\frac{3}{8}$ in. wide and 200 or 400 feet long. One inch of the width is occupied by the picture (also called the "frame"); the remainder: $\frac{3}{16}$ of an inch on each side, is used for holes (perforations). Projections, or sprockets, on revolving wheels fit into these holes, and move the film. In this way each small section of film is brought into place, held there, stationary, for the short, but very definite time needed for taking the picture, and then jerked away to make room for the next picture. Each photograph is $\frac{3}{4}$ in. high. There are, therefore, 16 photographs to each 12 in., or 16,000 in 1000 feet of reel.

The **shutter** of the camera has an important duty to perform. When the photographer turns the crank of the camera, a single "frame," 1 in. wide and $\frac{3}{4}$ in. high, is brought into line with the lens. The shutter of the camera is a revolving one, with openings in it. When an opening comes in line with the lens, the light passes through the opening and produces a photograph on the film. The film is not moving while the photograph is being taken, but in an instant the revolving shutter covers the section that has been exposed, and a new section is brought before the lens just in time to be exposed to light through an opening in the shutter. This process is repeated, each new section (frame) being jerked into position, exposed to light from the object being photographed, and then removed, say, 16 times a second. Each frame thus differs only slightly from those next to it, but the whole series shows a decided change in the object (Fig. 204).

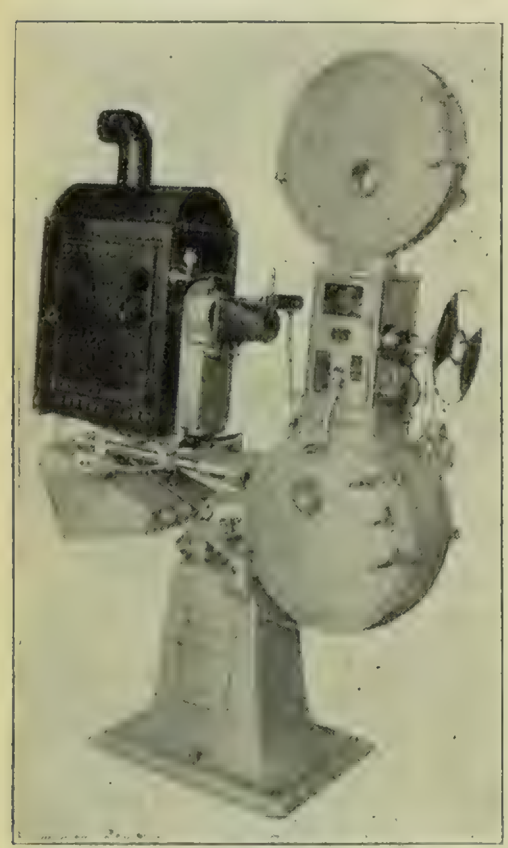


Courtesy of the Picture Service Corp.

FIG. 204.
Seven "frames" of film.

The pictures taken by the camera are negatives. The positive pictures, which make up the real film, are printed upon sensitized strips much as in ordinary photography.

The **projector** (Fig. 205) is a powerful arc-light lantern resembling that of a stereopticon. It has a **motor** for pulling each separate picture, or frame, into place, and a **shutter** with its revolutions so timed that its openings come into position at just the right instant. When a picture is thrown on the screen, it remains stationary for, say, $\frac{1}{32}$ of a second; then the next picture is jerked into place and left there for the same length of time. But in the meantime the shutter has covered the joint between the two pictures, and the audience does not notice the change.



Courtesy of the Enterprise Optical Manufacturing Company.

FIG. 205.

A motiograph projector. Notice its resemblance to the stereopticon.

The showing of motion pictures is successful not only because of the wonderfully perfect machinery of the projector, but also because of the behavior of the human eye and brain. Our eyes are like cameras, with the **retina,** the outspread end of the nerve of sight (see § 206), acting as the film. The image that is formed on the retina remains not only while a certain picture is on the screen, but lingers $\frac{1}{24}$ of a second after the picture is **actually removed.** Suppose that a picture remains on the screen $\frac{1}{32}$ of a second, and is then jerked away. The eye still "sees" the picture for $\frac{1}{24}$ of a second longer. Suppose that the shutter then covers the picture for $\frac{1}{32}$ of a second before allowing a new one to show. The old image still lingers in the brain for $\frac{1}{96}$ of a second ($\frac{1}{24} - \frac{1}{32}$) after the new picture is on the screen. Hence the brain says that the picture is continuous, for one picture "dissolves" into another.

The **movement** of an object is likewise a trick played upon the brain. The different stages of a movement (as when an actor raises his arm to take off his hat) are really done by jerks through perhaps 16 frames. But since the brain "sees" all the **stationary** parts of the scene in the same position in one frame after another, it thinks that it has actually seen the movements of the arm take place in the natural, regular manner.

209. The Microscope.— The magnifying glass (§ 206) is sometimes called a *simple* microscope, while the real microscope is said to be *compound*, because it has more than one lens. A microscope (Fig. 206) has the following parts:

(1) A **mirror**, usually **concave**, for collecting light rays and directing them to the object.

(2) An *object lens*, or **objective.**

(3) An **eye piece.**

(4) A **hollow tube,** at the top of which is the eye piece and at the bottom the objective.

(5) A **stage** for holding the object

(6) A screw **adjustment,** for bringing the objective to just the right distance from the object, so that the light will be properly focused for a clear image.

(7) A **base,** for supporting the tube.

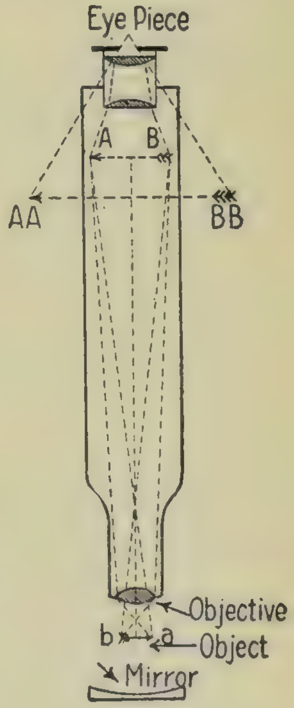


FIG. 206.

The compound microscope. The objective lens brings rays of light from the object a b to a focus to form the enlarged and reversed image A B; and the eye piece magnifies the image further to the size AA BB. Why is the image reversed?

The object (**a b** of Fig. 206) is fastened in a glass "slide," and lighted up by sunlight reflected from the mirror, or by a bright electric light. The rays from the object pass through the objective, by which they are bent and then focused to produce the enlarged image **A B.** Just as the magnifying glass enlarges an object placed near it (§ 206), so the eye piece of the microscope enlarges the image **A B** so that it seems to be magnified still further to the size **A A B B.**

If you follow the path of the light rays from **a b** *inside* the tube, you will see that they **cross** above the objective. As a result the image **A B,** and of course also **A A B B,** are completely **reversed,** just as in the pinhole camera (§ 207).

210. The Colors in Sunlight.— We have learned that we "see" objects, if they are not self-luminous, by the light they reflect to our eyes (§ 202). We have also thought of sunlight as **white.** The question then arises. Does sunlight contain **only** white rays? If so, why do so many objects that we see by sunlight have **color?** We can get an answer to our question regarding the composition of sunlight by letting a sunbeam pass through a three-sided piece of glass called a **prism** (Fig. 207).

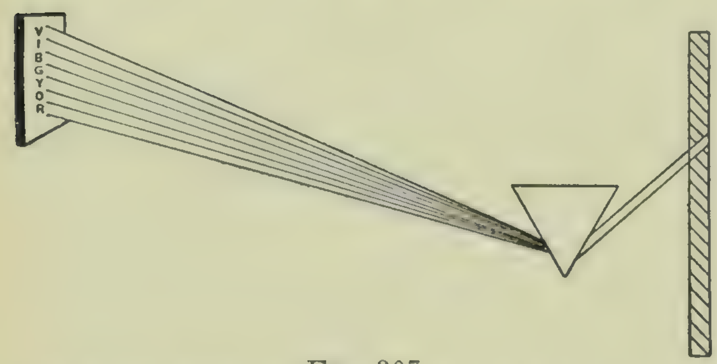


FIG. 207.
The glass prism breaks up white sunlight into light of seven well-marked colors: vibgyor.

If we admit the sunbeam through a narrow slit into a darkened room, and put the prism in its path, the image of the slit on the floor or the opposite wall will not be a single line, but a series of lines side by side, a wide **band;** and it will not be white, but will consist of bands of **different colors.** As the prism is placed in the figure, the highest band will be **violet** and the lowest, **red;** while between these there will be, in order, indigo, blue, green, yellow, and orange. The initials of these colors give us the word, **vibgyor.** You can see from the figure that the violet rays have been bent the most by the prism, and the red rays the least. These seven colors are called the **primary** colors, and the whole band of colors is called the **solar spectrum.** It was studied with great care by Newton.

How do light waves differ from one another, so that they can have such different colors? We know that when a metal like iron is heated, it first becomes **red** hot, and afterwards **white** hot. If heat and light are due to **waves,** it may be that the reason why the red color appears first is that red waves have the **slowest** rate of vibration. Then, when the temperature rises higher, the other waves may be added to the red ones to produce white light. The last to be added would be the violet waves. A study of light waves has proved this to be true. Red waves **have** the slowest rate of vibration and the **greatest length.** The longest red waves are about .00076 mm. long and have a rate of vibration of about 400 million millions per second. The violet waves are the **most rapid** in vibration: about 800 million millions per second, and also the **shortest:** down to about .00038 mm. The waves of the other colors come in order between these two. **All** light waves, of whatever color, also **heat** waves, move through space with the same velocity: about 300,000,000 meters, or 186,300 miles, in a second.

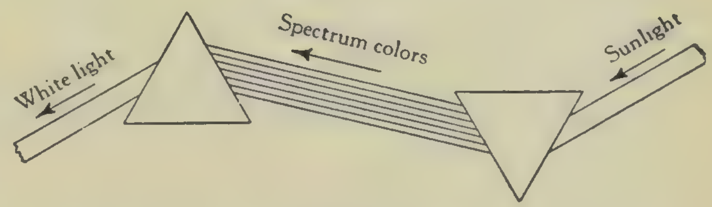


FIG. 208.
When sunlight which has been broken into its spectrum colors is passed through a reversing prism, the colors are reunited to produce white light.

Since white light consists of the primary colors, you may wonder if we can put waves having these colors together, and get **white** light. This has been done. If you put a second prism (Fig. 208), in a reverse position, in the path of the colored bands produced by the first prism, the colors are combined once more, and ordinary sunlight is the result. So we can prove, both by breaking up sunlight, and by putting the parts together, that white light is composed of light of different colors.

211. The Rainbow.— The finest solar spectrum we see in Nature is the rainbow. In order to see a rainbow we must look at falling rain, and the sun must be behind us, 42° or less from the horizon. Is this half the distance from the horizon to the zenith? See § 147. You can often see a small rainbow in the spray of a waterfall or of a lawn sprinkler.

In forming a rainbow each drop acts both as a **lens** and as a **mirror.** It **refracts** the sun's rays as they enter the drop, **reflects** them from side to side within the drop, and then refracts them as they re-enter the air. From the **outside** of the rainbow arch only **red** rays reach our eyes. The drops **inside** the arch send to us, in order, orange, yellow, green, blue, and indigo rays. The **lowest** drops send the **violet** rays. In Nature **two** bows are often seen together: a **primary** one, red on the outside of the arch and violet on the inside, and a **secondary** one, outside the primary one, and with the colors of the primary bow in **reverse order.**

A **halo,** or ring of light, around the moon or the sun is probably due to a breaking up of light by the thin, icy clouds of the upper atmosphere.

212. Why Objects Have Color.— Have you ever tried to determine the exact color of a sample of cloth or thread in artificial light? If so, you have probably found that the best plan is to carry the material to a window, in order to see what the color really is in daylight. Find out, if possible, how "daylight lamps," now being used in many stores, are constructed.

You can produce an intense **yellow** light by heating common salt in a colorless flame like that of the Bunsen burner or an alcohol lamp.

The best way is to soak a strip of asbestos paper or blotting paper in a salt solution, to dry the paper, and then to hold it in the flame. If in this yellow light you examine strips of paper or cloth known to be red, yellow, and blue, you will find that only the yellow strips have a natural look, while the others are almost **black.**

If you examine colored objects in **red** light, such as that used in a photographer's developing room (see § 207), you will find that only the red objects look red; all the others will be nearly black.

As striking as any of these is the **mercury-vapor lamp** used in many factories and photographers' studios. Its light is blue-green. In it the skin has a ghastly color, the pink of the lips is almost black, and only white and black appear natural.

As you think over these facts, you will decide that what we call the **color** of an object is the effect it produces upon our eyes in white daylight. This effect depends upon the fabric and the dye, also upon the **kind of light** used. A **red** object has this color because it absorbs other light waves better than it does red ones; as a result the light which it reflects has a great excess of red waves. But unless the light by which we see the object contains red waves, the object cannot appear red. An object is **yellow** because it throws back yellow waves and absorbs the others.

If a body throws back light rays of all colors, it is **white.** If it absorbs all, it is **black.** If it reflects nearly all, it is **light gray. Lampblack,** or soot, a form of the element **carbon,** is a good absorber of light; a **silver** mirror is an almost perfect reflector (see § 204).

Two colors that yield white light when mixed are called **complementary** colors. Such are red and blue-green, yellow and blue-indigo, orange and light-blue, green-yellow and violet.

It is possible to break up other light besides sunlight by passing it through a **prism** (see § 210). If gas light and electric light are separated into their primary colors, we find that they contain the same colors as sunlight, but in a **different proportion.** Hence certain shades do not appear the same as in sunlight. The spectrum of the mercury-vapor lamp has no red in it; this fact accounts for the effect of the light.

213. The Colors of the Sky.— As we think of the changing colors of the sky, we see that they can hardly be brought about by changes in the sun's light; this probably comes to us year after year without noticeable alteration. But the sun's light does not reach us until it has gone through the earth's atmosphere. We must remind ourselves again that we are living at the bottom of an ocean (see § 7), and that what comes to us from outside this ocean is changed by passing through it. The *blue* rays of sunlight seem to be scattered most by the extremely minute particles of atmospheric dust which they encounter, or are reflected to our eyes. Sometimes the sky is *indigo*, rather than blue. This atmospheric dust may be ordinary, solid dust, or fine particles (mist) of water and ice (see § 133). If there is too much dust, the sky is not blue. Near the sun and near the horizon the sky is ordinarily *light gray.*

At sunrise and sunset the sun's rays come to us very **obliquely,** and the colors we see, especially if there is sufficient atmospheric dust, are red, orange, and yellow. These are the colors of greatest wave lengths and slowest rate of vibration; they are refracted, or bent, least.

In 1883 the volcano of Krakatoa, in Java, had a violent explosion, and an enormous amount of very fine dust was blown into the upper atmosphere. This settled so slowly that it spread around the whole globe, producing brilliant sunset effects for three years.

214. Trapping Sunlight.— Fig. 209 shows a "cold frame," in which vegetables may be grown in the early spring, while the weather is still too cold for outdoor planting. It consists of a box having no bottom, but having a glass cover. It is really a **trap** for sunlight.

Sunlight brings us **heat** waves as well as light waves. These vibrate too slowly to give off light (see § 210). Glass cuts off the heat waves to a great extent, as we can prove by holding a pane of glass between us and a hot stove; but it lets light waves pass. Now, when sunlight strikes the glass cover of a cold frame, the light waves pass through and are largely absorbed by the soil. They are thus changed into heat waves, which remain in the cold frame to warm it.

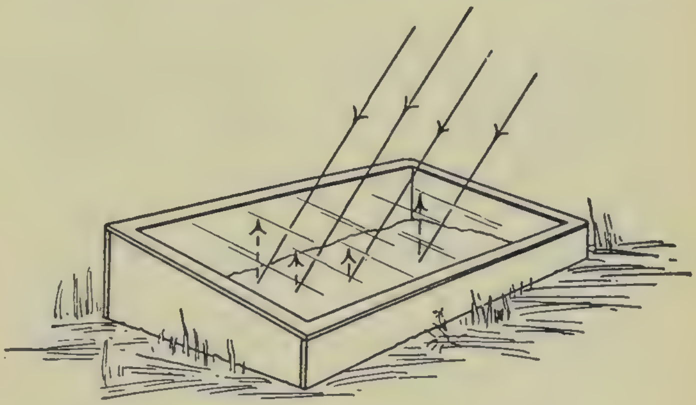


Fig. 209.
The rays of sunlight pass through the glass and are absorbed by the ground. They are thus changed into heat for the growing plant.

We have already learned (see § 128) that the water vapor and impurities of the atmosphere act like glass in making sunlight a prisoner, and thus maintaining the temperature of the earth's surface. Without them a rapid radiation of the heat received from the sun would take place, and a chill would result which would rapidly put an end to all animal and vegetable life.

215. Summary.— **Window glass** is an agent of health and civilization.

Artificial illumination lengthens the daytime.

Lighting has been done by open fires, oils, candles, petroleum products, illuminating gas and other gases, and electricity.

We get the **candle power** of a lamp by means of a **photometer.**

Incandescent mantles are heated white hot by colorless flames, such as the Bunsen and gasoline flames.

The **gas meter** records the amount of gas that goes through it.

Visible bodies are either **self-luminous** or **illuminated** by other bodies.

Objects may be **transparent, translucent,** or **opaque.**

Light travels in straight lines, about 186,300 miles a second.

Daylight is sunlight irregularly reflected by objects.

Sunlight brings us heat waves and waves having chemical effects as well as light.

Light is **reflected** at the **same angle** as that at which it strikes the reflecting surface, but in a different direction.

In a **plane mirror** the image is right side up, but the right and left sides are **reversed.**

Our **judgment** corrects the evidence of our sight.

A **periscope** is a tube having mirrors to reflect light around corners.

When light passes obliquely from one transparent body to another of **different density,** it is bent, or **refracted.**

A **lens** thickest in the middle brings light rays to a focus; one thickest at the edges spreads them apart.

In a **magnifying glass** we see an enlarged, natural image.

The eye's **crystalline lens** changes its curvature and focus.

A **camera** is a box in which the image of an object is brought to a focus upon a sensitive plate or film. The image is completely **reversed,** because the light rays cross one another.

For a **motion picture** several "instantaneous" photographs of a moving object are taken on a series of films. When these films are shown in order and close together, the **image** moves as the object did.

The **microscope** gives a much enlarged, but completely reversed, image of the object magnified.

White light is composed of many colors, into which it is broken up by a **prism.** The band of colors obtained from sunlight is the **solar spectrum.** A **rainbow** is a spectrum on a large scale.

The **color** of a body is caused by the rays it cannot absorb, but must reflect.

Light waves are changed into **heat** waves by being absorbed.

216. Exercises.—1. Why do we believe that the moon is not self-luminous?

2. Classify the following as transparent, translucent, or opaque: ice, snow, gasoline, milk, lead, your finger nails, tissue paper, skin, ink, carbon dioxide, and a solution of blue vitriol.

3. Iron becomes red hot at about 525° C. Is it self-luminous or illuminated if we see it at 500°? At 600°?

4. I see a carpenter, down the street, driving nails; but I hear the sound of each blow just as I see his hammer raised for the next blow. Why?

5. I see a flash of lightning 5 seconds before I hear the thunder. How far away is the thunder cloud?

6. Why is the shadow cast by a lamp of small diameter, such as an electric bulb, so distinct? See § 155.

7. I sit 5 feet from a lamp while my brother is 1 foot from it. How much more light does he get on a page than I?

8. In measuring the candle power of a lamp (Fig. 188) I find that a candle at the distance of 1 foot casts a shadow just as dark as one cast by a lamp 6 feet away. What is the lamp's candle power?

9. A mirror on a dresser is 30 inches above the floor. How do you tilt the mirror to get a full-length view of yourself? Why do you step back from the dresser?

10. How long would it take light to go once around the earth at the equator?

11. If you see a rainbow at 8 A.M., in what part of the sky will it be? At 4:30 P.M.?

12. Do we ever "see" the sun after it has set, and before it has risen?

13. Is a water surface ever a mirror? A varnished floor? Name other mirrors.

14. Might glass bottles left in the woods ever cause forest fires? How?

15. Why does a photographer use red light in his dark room?

16. Give all the reasons why vegetables can be raised so much earlier in a "cold frame" than in the open air.

17. Name all the cases given in this chapter which show that the evidence of our eyes must be corrected by our judgment.

18. Is it safe to step off into water the depth of which seems just "up to your neck"?

217. Projects.— 1. Make a periscope, and demonstrate how it works.

2. Show how a candle may be made to appear to burn in water (§ 204). Devise another combination of the same kind.

3. Demonstrate to the class the effect of a piece of plate glass on the appearance of a wire over a part of which it is laid.

4. Demonstrate to the class that a person who sees the image of another in a plane mirror can also be seen by the other person, and explain why.

5. Demonstrate that the effect of pouring water into a dish is to make the dish seem more shallow and to bring into view objects invisible before (§ 205).

6. Show how paper or chips can be set on fire by a burning lens.

7. Prepare in writing the "history" of a particular rainbow you have seen: the weather conditions, time of day, position of the sun, height of sun above horizon, extent of rainbow, time of duration, order of colors, whether it was single or double, and so on.

8. Demonstrate to the class, either in school or in an establishment using it, the mercury-vapor lamp and its effects upon colored objects.

9. Prepare a glass-covered box of soil (cold frame) out of doors, and show how the temperature inside the box compares with that outside when the sun is shining on the glass.

10. Prepare three small "cold frames," and find by trial what the best position of the glass cover is with respect to the sun's rays: parallel with them, at an angle of 45°, or perpendicular to them, so as to get the highest temperature inside.

11. Set up a new "gas mantle" before the class, and explain its action.

12. Show the class how the Bunsen flame is colored by common salt, strontium chloride, and barium chloride solutions. Soak strips

of asbestos paper in each of the solutions, dry them on a radiator, and then hold the strips, one at a time, in the flame.

13. Demonstrate to the class the effect of looking at materials of different colors in colored light.

14. Show the class the effect of standing before a mirror and watching the image of your hand as you write your name.

15. Determine by trial the comparative distance at which you must put 4 candles (set close together), so that their shadow shall be just as dark as that of one candle by itself. Use "Christmas" candles or "birthday" candles. See § 199.

16. Determine the candle power of a small kerosene lamp, or of a "birthday" candle, and prove it to the class.

17. Demonstrate to the class that a small area of light gives a more distinct shadow than a large one.

18. Report on some cases of your own observation that sound travels more slowly than light.

19. Make, and demonstrate the working of, a pinhole camera.

20. Show that a burning candle forms an image when its light passes through a pinhole in a card. Use a large card.

21. Demonstrate to the class how to make a positive print from a negative.

22. Show the construction and operation of a camera.

23. Find the position of a reading glass or magnifying lens with respect to the object and your eye, when you see the magnified object in its natural position. When you see the object in reversed position.

24. With a glass pendant, or a dish of cut glass, or some other "homely" prism, demonstrate to the class the formation of the solar spectrum.

25. By some method of your own demonstrate to the class that the angle of a beam of light before reflection is the same as after reflection.

26. Show the class how the image of an object is distorted if it is partly in, and partly out of, water.

27. Find, from some book describing glass blowing, how to blow a bulb on the end of a glass tube, and demonstrate it to the class.

28. Demonstrate the working of a central-draft kerosene burner.

29. Prepare a paper on the working of a motion-picture machine and read it to the class.

30. Show the class a film prepared for motion pictures, and tell how they were made.

31. Prepare a report upon the colors of the sky at sunrise and sunset, and in what way they indicate what the weather is to be.

32. Demonstrate to the class the construction and operation of a compound microscope.

218. References.—BELL: *Photography for Beginners.* Books on Inventions and Inventors (see § 6). EALAND: *Romance of the Microscope.* EASTMAN KODAK COMPANY: *How to Make Good Pictures.* LESCARBOURA: *Motion Pictures.* MILLIKAN AND GALE: *A First Course in Physics.* TALBOT: *Motion Pictures, How They Are Made and Worked.* TOWER, SMITH, TURTON, AND COPE: *Physics.*

CHAPTER XIII

WHAT WE HEAR

219. What Causes Sound?— What is the nature of sound? Is sound, like light, given off only by certain bodies? The best way to get the answer to these questions is to carry out a few **experiments:**

Hold a table fork or a tuning fork lightly by the handle, and strike its prongs (**tines**) against a table. Then hold the fork near your ear, and note the ringing sound it gives out. Strike the fork again, and hold it against a sheet of paper. Set it to sounding again, and this time let its prongs touch the edge of an empty water glass. Also try its effect upon the surface of some water (Fig. 210). The results show that the sounding fork strikes with rapid blows the objects it touches, and sets them in motion. The fork is, in fact, moving rapidly to and fro, **vibrating.**

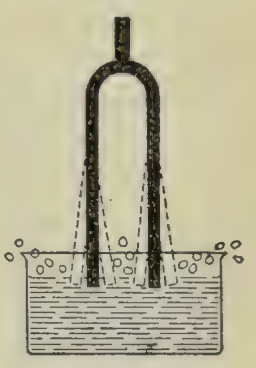


FIG. 210.
The sounding tuning fork is in rapid vibration and scatters the water in contact with it.

All sound is due to the vibration of some material. It may be the air vibrating in thunder, or it may be a violin string vibrating because touched by the rosined bow. When a piano key is pressed, the corresponding wire is struck and set in vibration. In speaking and singing we set two membranes in the throat (the vocal cords) into vibration by forcing air through a slit between them. The rapid movement of a bell struck by a hammer produces the note of the bell. In all these cases the sounding body sets the air next it in vibration, and the air vibration, reaching our ears, causes us to hear. The structure of the ear is given in Chapter XXII.

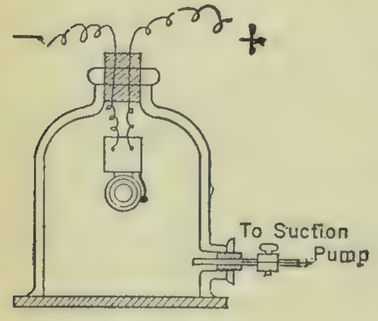


FIG. 211.
The sound given off by the bell grows fainter and fainter as we remove the air from the jar.

How do we know that air carries sound? If an electric bell is set to ringing inside a bell jar (Fig. 211), and the air is nearly all removed by an air pump, the sound grows feeble. It becomes stronger again when air is admitted. A vacuum does not carry sound.

Does any material besides air carry sound? If you hold your ear close to one end of a long **iron** pipe, such as a steam or water pipe, and have some one scratch or tap the other end of the pipe lightly, you can hear the sound better than if your ear is away from the pipe. The same would be true if you used a long, **wooden** pole. Wood and iron conduct sound better than air does. **Water** is also a better conductor of sound than air is; the clashing together of two stones under water produces a louder sound than in air. A **string** telephone, made out of two tin cans and a long string, enables persons to talk together at a distance of several hundred feet. The string must be tightly stretched, and must not touch anything but the cans. A waxed linen thread or a fine wire may also be used. Through air, under ordinary conditions, sound travels about 1,126 feet in a second; through water, about 4,600 feet; through iron, about 17,000 feet.

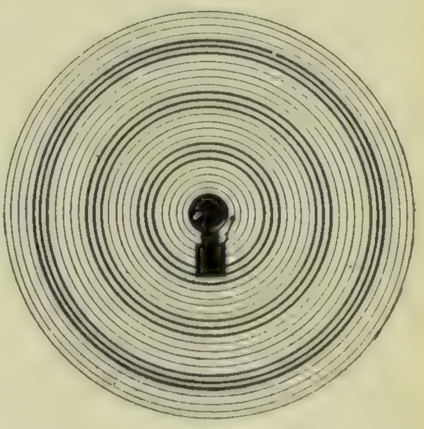


FIG. 212.
Sound waves spread in spheres that grow larger and larger. Each wave consists of a compression and then an expansion of air.

220. Sound Travels in Waves.

— When a sound is produced, it can be heard in all directions.

This is due to the fact that sound waves begin as small spheres (Fig. 212) which grow larger and larger as they move out from the sounding body. But as the spheres grow larger, more and more air must be set in motion. As a result the motion of a given volume of air becomes smaller and smaller. Finally the motion of the air is too small to affect the ear. The sound has "died out" with distance.

How does air move when it carries sound? It cannot go as a wind does, by the forward movement of the whole body of air. Except in the case of very loud sounds, we do not feel any forward movement at all. To understand the movement of sound waves we must remember that air is **elastic**. It can be compressed; but it expands instantly when the pressure is removed (§ 11). The sudden shock given the air by a sounding body pushes the nearby particles of air closer together, producing a layer of compressed air, spherical in shape. This layer then expands and in doing so gives a rapid **push** to the next layer of air. The sound wave thus travels outward as a series of short, rapid compressions and expansions of air. The air particles may move only a **very short** distance, but as they give their motion to the particles next to them, and these in turn to those still farther on, the **wave** of sound may travel a great distance.

221. What Wave Motion is Like.— Sound, as we have just learned, comes to us in waves; heat, light, and wireless messages likewise reach us as a result of wave motion. We therefore need to know a little better what wave motion is like.

Very likely each of us has thrown a stone into a pool or pond of quiet water and seen the effect. Waves are produced which travel toward the shore in ever-widening circles. Even after the water at the center of disturbance has become quiet, we can still see an up-and-down motion of floating objects near the shore. Energy has been carried from the falling stone to the floating objects by wave motion.

Let us study the cross section of some water waves shown in Fig. 213. The figure shows that a stone pushes down the water under it, and causes the wave motion. We call **A, B,** and **C,** the highest parts of the waves, the **crests; D, E,** and **F,** the lowest parts of the waves, we call **troughs.** If we measure the distance between **A** and **B, B** and **C,** and so on, we find it always the same. This distance: **X,** is one **wave length.** It may be measured in feet, meters, or other units.

Fig. 214 shows a rod set upright in the water. If we note carefully the rising and falling of waves on such a rod, we find that the motion is regular. The motion of the water, from crest to trough, and then back to crest, is one **cycle** of the wave. If the water rises twice in a second to the point **A,** we say that the wave has a **frequency** of 2 cycles per second. If you give the matter a little thought, you will see that we obtain the speed, or **velocity,** with which the wave moves forward by multiplying the wave length by the frequency. Thus, if the wave length is 2 feet, and there are 2 cycles per second, the velocity is 4 feet per second.

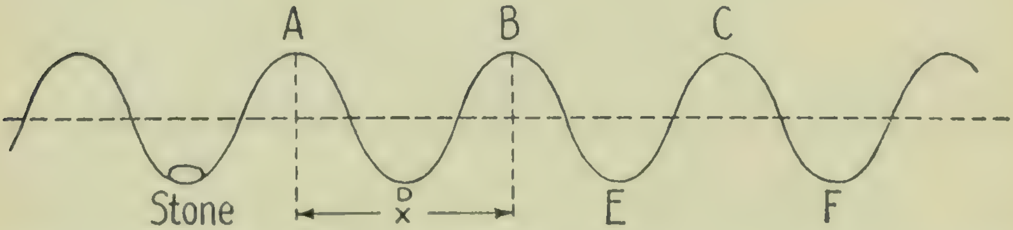


FIG. 213.

The vibration in water waves is up-and-down; but the wave movement is forward. Water waves are transverse. The motion of the air in sound waves is forward and back; they are longitudinal waves.

$$\textbf{Velocity}=\textbf{Wave Length}\times\textbf{Frequency}$$

We can also state the rule in the following way:

$$\textbf{Wave Length}=\frac{\textbf{Velocity}}{\textbf{Frequency}}$$

These ideas of wave length, frequency, cycle, and velocity apply to all waves.

222. What are Echoes?— If you stand in an open place, and shout, you often hear the sound return, after a second or two, as an **echo.** The sound waves travel through the air until they strike a cliff, or the side of a building, or some other surface; then they are reflected back to you, much as light waves are. To produce an echo you must be far enough away to allow your shout to cease before the reflected sound returns.

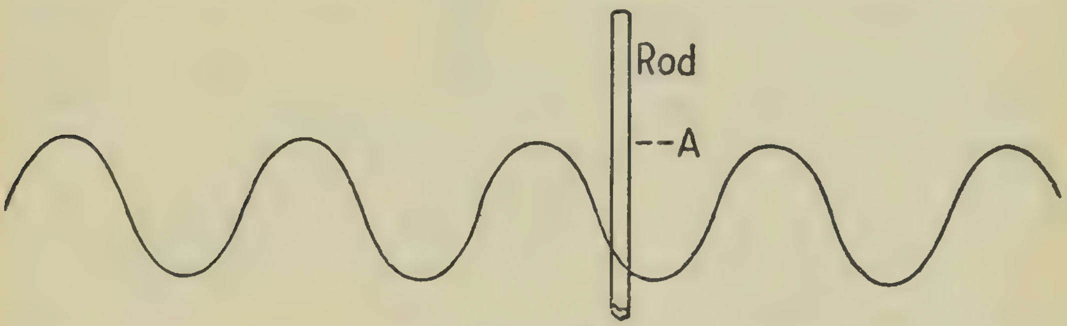


FIG. 214.
From crest to trough and then back to crest is one cycle of the wave. It is sometimes called a "double vibration."

In a **small** room the sound waves return so quickly that the echo blends with the original sound, and you do not notice it. In some **large** halls you get the echo of one word while another is being spoken. The result is very confusing. Architects try to construct walls so that they shall not give echoes. At the same time, the walls of a hall aid a speaker by their reflecting surfaces; it is much easier to speak indoors than out in the open. If a hall forms echoes, **draperies** are often hung across it to break up the sound, or **wires** are strung across it. In the **mountains** many echoes of a sound may often be heard as the sound waves are thrown from one cliff to another. The rumbling of thunder is the original sound combined with the echoes produced when the sound waves are reflected from the clouds and the earth.

Since sound travels through **water** as well as through air, it can be reflected by objects under water as well as by objects, such as cliffs, in the air. We can thus get **water echoes** as well as air echoes. This fact has been made use of in the construction of apparatus for measuring the depth of the ocean. If the operator finds the time required for a sound to travel to the ocean bottom and to return, and knows also the rate at which sound travels in the water, he can calculate the depth (§ 219).

223. Noises and Tones.—When a chair is overturned or a tray of dishes is dropped, the sound waves produced are irregular, and we hear a **noise.** But when a skillful player draws a bow over a violin string, the string vibrates regularly, with the same time interval between vibrations. These regular waves produce a pleasant effect, and we call it a **tone.** Any hard body: a dish, a stone, a wire, a car wheel, or a block of wood, gives out a tone when struck. Prove this. What is a xylophone? A bell?

By the **pitch** of a tone we mean whether it is high, or low. Pitch is the result of the **frequency** of the vibrations. "Middle C" of a piano is produced by a wire vibrating 256 times per second. The usual range of the human voice is from about 60 vibrations per second (very lowest bass) to perhaps 1,300 vibrations (high soprano). We can **hear** sounds due to a much greater frequency than we can produce. Thus, the high notes of a violin, the noise of a cricket, and the screech of a locomotive are due to thousands of vibrations in a second. When the number of vibrations is less than about 16 per second, or more than about 40,000, the human ear does not hear them.

224. Some Musical Instruments.— If you name all the kinds of musical instruments you can think of, you will find they can be grouped into a few **classes.** What are some of the **stringed** instruments, which really consist of vibrating strings or wires? What are the **reed** instruments, in which the vibrating part is a reed or diaphragm? Which instruments really consist of vibrating columns of **air**, and are called *air-chambered*, or **wind** instruments? Can you put the bell, the xylophone, the drum, and the tuning fork into any of these groups? In which does the voice belong? The phonograph?

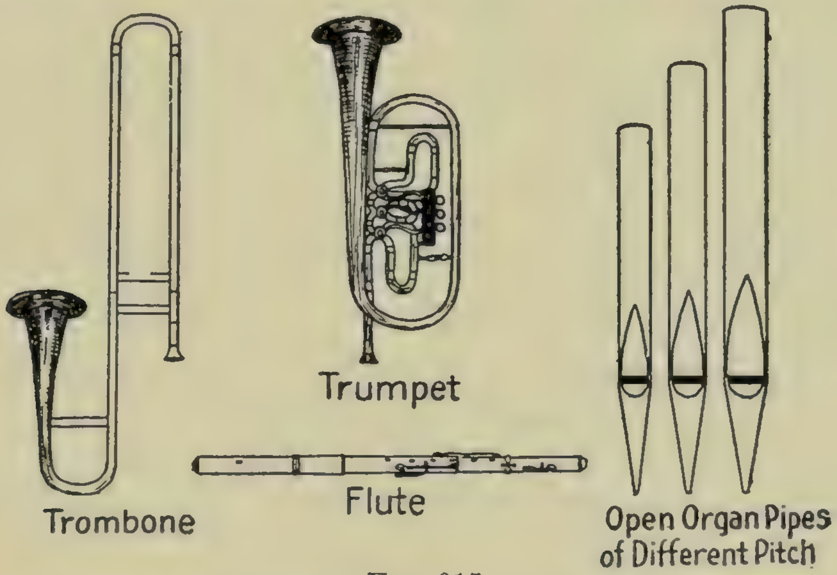

Trumpet
Trombone
Flute
Open Organ Pipes of Different Pitch

FIG. 215.
Wind instruments, in which air columns of different lengths give, by their vibration, different notes.

In wind instruments there may be either open, or closed, pipes. You can make a whistle by blowing over the open end of a hollow tube of glass, wood, or metal. The pipe organ has such tubes. Other wind instruments are the flute, clarinet, bugle, cornet, and trombone (Fig. 215).

In order to produce the different notes on a **flute** the player blows into the instrument, and opens and closes holes in its side. Thus he makes air columns of different lengths vibrate. In the **trombone** the player slides portions of one pipe back and forth, and thus obtains the right lengths of the air columns needed to give the different notes. **A pipe organ** must have a different pipe for each note.

Each instrument has its own **quality** of tone. Even when the number of vibrations is the same in two instruments, say in the bugle and the piano, so that the instruments sound the same pitch, or note, still the **quality** is so different that you have no difficulty in telling the note of the one instrument from that of the other. The quality of different human voices likewise differs so much that we tell our friends apart by their voices.

225. The Phonograph.— We have all seen a phonograph in operation. A disk of hard material (the **record**) is laid upon a turntable which is run by a spring or motor. The disk has a spiral groove into which we put the needle point of the reproducer. As the disk revolves under the needle, the phonograph reproduces vocal or instrumental music, or spoken words, with wonderful exactness of loudness, pitch, and quality.

The cause of the sound in a phonograph is the **reproducer,** which consists essentially of a needle, a **diaphragm,** and a horn. As the spiral groove moves past the needle, all of its little inequalities produce movements in the needle, and the needle, in turn, transfers these movements to the diaphragm. The sound waves sent out by the vibrating diaphragm are strengthened by the horn attached to it, so that we can hear them.

The construction of the record requires careful work. The instrument or performer sends forth sound waves to the recording apparatus. This, like the reproducer, consists of a horn, a diaphragm, and a needle. As the diaphragm vibrates, it gives a wavy motion to the needle, and the needle, in turn, traces a wavy groove in a wax-covered disk that is made to revolve under it. The problem is then how to transfer the impression made in wax to some hard material. One way is to dust the wax with something to make it a conductor of electricity, and then to electroplate it with copper (see § 180). As a result a hard mold is obtained.

The records which we buy are made from the hard mold. Disks of hard rubber or some substitute for it are softened by heat and pressed against the mold. Thus they receive an exact copy of the wax impression. Then, when we place the record in the phonograph, the needle of the reproducer retraces the path made by the recording needle, and we get back the original sounds.

226. The Telephone.— No instrument of sound, except the human voice and ear, has done so much to build up the commercial, industrial, and social life of our day as the **telephone.** Think of the extra steps that would be necessary if all of us were suddenly to be without this instrument. The telephone was invented in 1875 by Alexander Graham Bell and Elisha Gray.

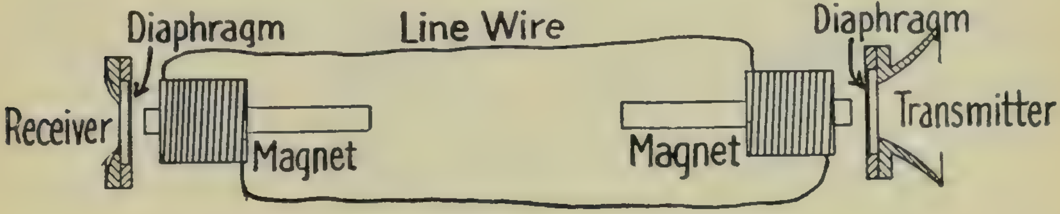


FIG. 216.
The simple telephone. The vibrations of the iron diaphragm of the transmitter are repeated by the diaphragm of the receiver.

The necessary parts of the simple telephone are shown in Fig. 216. When you speak into the mouthpiece of the transmitter, you make a thin diaphragm of soft iron vibrate, as in the recorder of the phonograph (see § 225). Near the diaphragm is a permanent magnet. The vibration of the iron diaphragm across the lines of force surrounding the magnet **induces** electric currents in the **coil** around the magnet (see §§ 169 and 185). These induced currents travel over the line wire to the telephone receiver at the other end. Inside this receiver there are also a **coil,** a **magnet,** and a **diaphragm.** The incoming currents set up disturbances in the lines of force of the magnet, so that the diaphragm of the receiver is made to **vibrate.** The vibrations of this second diaphragm are exactly like those of the diaphragm in the transmitter. Therefore the sound heard at the receiver is exactly like the one you made at the transmitter. Can you see that one end of the telephone resembles a **dynamo** and the other a **motor?** At one end motion is changed into an electric current; while at the other end an electric current is changed into motion (see § 187). Which is which?

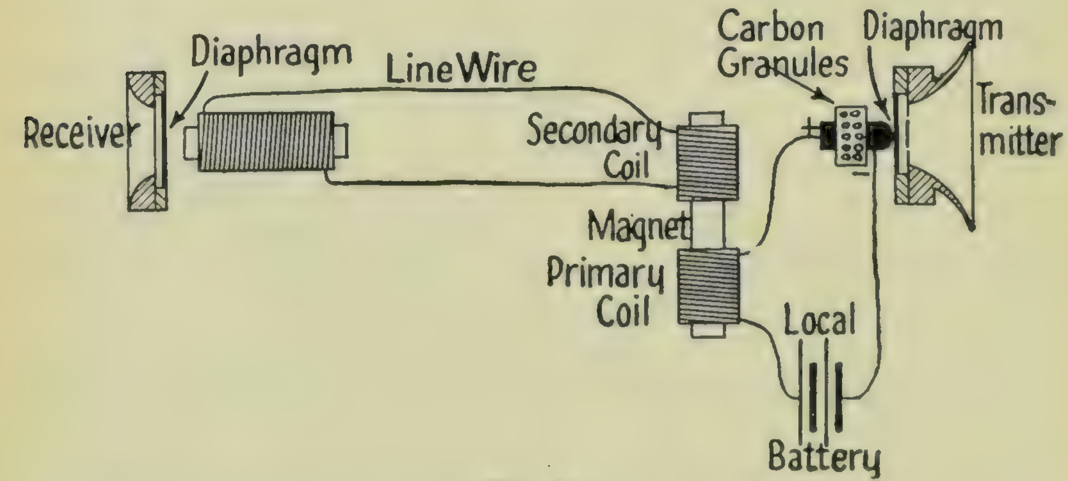


FIG. 217.

Diagram of a modern telephone with a local battery. The battery adds its energy to the currents produced by the transmitter; hence sounds can be carried farther than in the simple telephone.

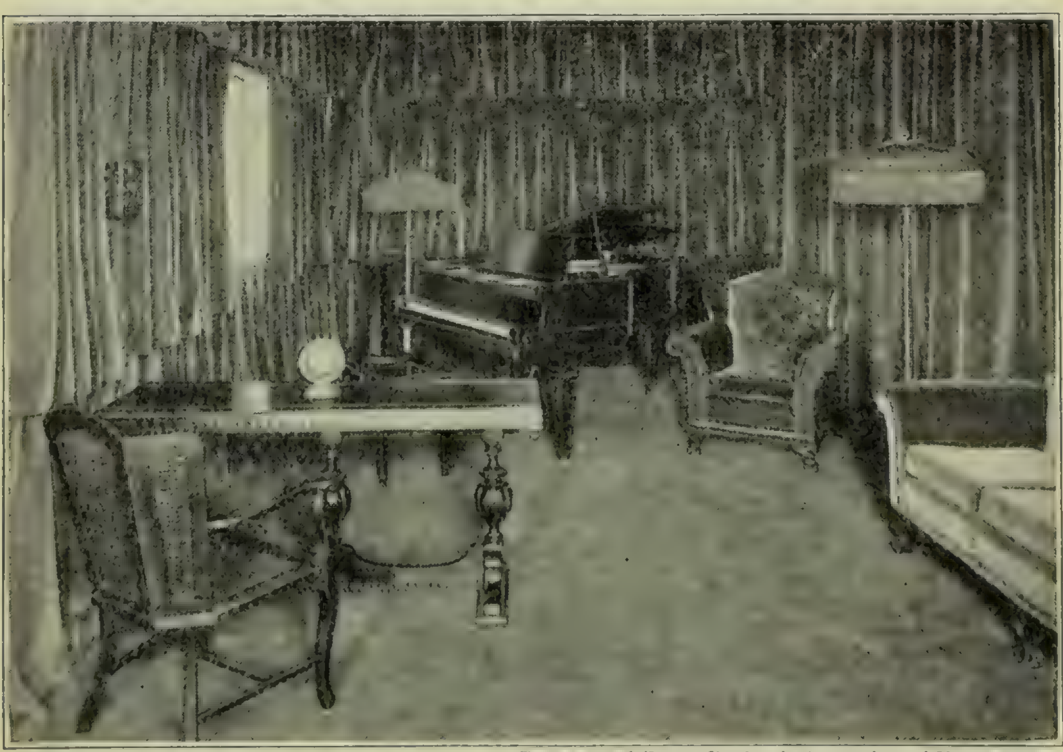
The Modern Telephone.— It is not possible to send messages very far with the simple telephone, because the currents induced by the transmitter are too feeble. Hence some additional apparatus must be used (Fig. 217). The two most important things added are (1) a **battery,** called the **local** battery and (2) a small box containing **grains of carbon.** The battery current passes through the box of carbon grains, as well as through the primary coil surrounding the magnet.

As the diaphragm of the transmitter vibrates, it presses now more, now less, against the box full of grains of carbon. When the diaphragm, in its vibration, presses hard against the grains, they are forced closer together, and the electric current from the battery passes through them more easily. When, however, the diaphragm springs back, the carbon grains move farther apart, and the current meets with more resistance. These changes in the strength of the current in the battery circuit (we call it the **primary** circuit) of course affect the magnet of that circuit, and also **induce** changes in the magnet and wire of the main telephone line, which form the **secondary** circuit. When these changes appear at the magnet of the receiver, they set up vibrations in the receiver diaphragm which are just like those that were formed in the transmitter. The current induced in the secondary circuit is an **alternating** one (§ 185).

When sound waves become associated with an electric current, as in the telephone transmitter, we say that the sound waves are **impressed** upon the current. The local battery used in the modern telephone **strengthens** the weak induced currents produced in the circuit, because it adds its own **energy** to these currents. So the sound effects that had only a feeble current to carry them now have a **strong** current to do the work. As a result they travel much farther, and the telephone can carry long-distance messages.

227. Radio Communication.— What does "radio" mean to you? To some of us it means a wooden cabinet (perhaps the same cabinet contains a phonograph) having on its panel some dials and knobs by the adjustment of which we can hear music and speeches, market and weather reports, perhaps the sounds of football games, 20, 100, or 1000 miles away. Others of us have probably bought at the shops the interesting, well-made pieces of apparatus that make up a radio set, and have not only the enjoyment of the radiophone in operation, but the added satisfaction of having successfully put its parts together. Then there is the boy or girl whose radio equipment may properly be called "home-made": an assembly of crystal and amplifier, coils and condenser, batteries and tuning dial, which, in spite of many handicaps, really works, and allows the owner to share in the enjoyment received by those having more expensive sets. This last one—the real amateur—probably gets more out of radio than the others; he has learned his radio *by heart.*

Two causes have combined to give radio its present popularity. One is the fact that people cannot help thinking of communication **without wires** as little short of magic. To be sure, as we have already learned, a body which has an electric charge, or a wire that is carrying an electric current, **induces** an effect upon bodies placed near it (see §§ 174 and 181); but people in general do not think of this; besides, the distance is so much greater in the case of wireless communication.



Courtesy of Sears-Roebuck Agricultural Foundation.

FIG. 218.

Broadcasting studio with microphone on table.

The **second** cause for the great interest in radio is that the receiving of messages and programs is **free** to any one who has a receiving set.

A recent writer suggests that, after all is said, we must conclude that the popularity of the radiophone is due chiefly to the boys and girls who have experimented with it.

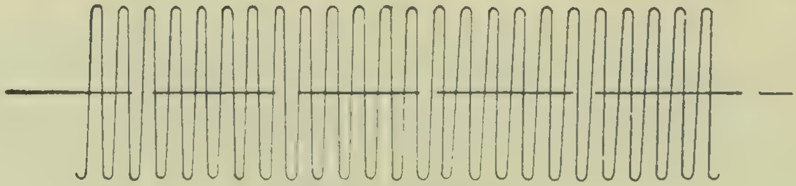
228. Wireless Waves. — The name "radio" comes from the same source as *radium*, *radiant*, and *radiation* (§ 42). We have already learned that there are two ways in which **heat** is carried from one place to another: (1) by conduction, along some material which we call the conductor; (2) by radiation, through space. We are more accustomed to think of electricity as being **conducted** along wires; we must also think of it as being **radiated** in waves, as heat and light are (§§ 203 and 212).

In § 221 we learned something of water waves and sound waves, together with the meaning of *velocity*, *wave length*, and *frequency*. We use the same terms in speaking of electric waves. It may not seem possible that heat waves and light waves are closely related to electric waves; but it is true. They are all grouped together as **electromagnetic** waves. All three have the same velocity through space: about 186,300 miles, or 300,000,000 meters, a second. It was because scientists had discovered this fact that Marconi was able to devise the wireless telegraph.

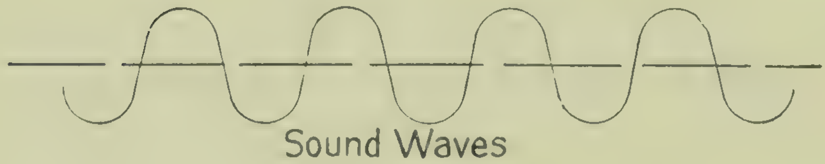
We have learned that velocity is equal to wave length multiplied by frequency (§ 221). Since the velocity of the three kinds of electromagnetic waves: light waves, heat waves, and electric waves, is the same, the differences between them must be due to wave length and frequency of vibration. The greater the wave length, the less the frequency (§ 210). Light waves are the **shortest**, and have the greatest frequency. Heat waves have a greater wave length than light waves, but a smaller frequency of vibration. **Longest** of all are electric waves.

If we know the frequency of any of these waves, we can calculate their wave length. Thus, a wave having a frequency of 500,000 cycles a second, has a wave length of $\frac{300000000}{500000}$ or 600 meters.

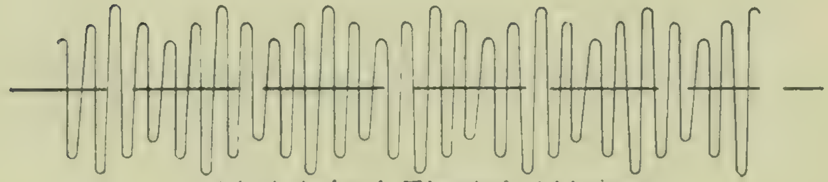
229. Electric Waves and Sound Waves.— The electric waves used in radio communication have frequencies of from 10,000 to perhaps 3,000,000 cycles per second. A frequency above 10,000 cycles per second is called a high, or radio, frequency. As compared with this the frequency of an ordinary lighting circuit: 60 cycles per second, is, of course, very low. If electric waves have a frequency of less than 10,000 cycles per second, they are said to be of audio frequency. This name means "hearing" frequency, and is used for the following reason:



Electric Waves



Sound Waves



Modulated Electric Waves

FIG. 219.

The impressed sound wave is carried by a series, or train, of electric waves, and modifies, or modulates, them.

In order that electric waves may carry sounds they must have the effects of sound waves stamped upon them, just as in the telephone

(§ 226 and Fig. 217). We say that the sound waves are **impressed upon** the electric waves (Fig. 219). But, as we learned in § 223, if the vibrations of a body become too frequent, we cannot hear a sound at all. Radio waves of high frequency, even though they have been changed by sound waves, pass right through a telephone receiver without producing a sound. If, however, the frequency of such radio waves can be reduced to a sufficiently small number of vibrations, say, less than 10,000 per second, the sounds impressed upon the waves can make their presence known. They can set up vibrations in the diaphragms of the head telephones or the loud speaker of the receiving set, and be **heard.**

230. How Wireless Waves are Produced.— We now want to know something of the way in which the electric waves used for radio communication are produced. The sending, or transmitting, station must have apparatus for producing a current; it must also have a wire, or set of wires, called the **aerial** (ā-ēr′ĭ-ăl), or antenna, from which the electric waves can be sent. The aerial is insulated from the poles or trees, or buildings which support it; but it is connected, by means of a wire, with the ground.

The electric current used in producing wireless waves must be an **alternating** one. For the large wireless-telegraph and broadcasting stations a dynamo that generates an alternating current is generally used; for smaller stations storage or dry batteries furnish the current. The current from a battery is a **direct** current; it must be changed to an alternating one. Both the battery and the dynamo currents must be changed to **high-frequency** currents vibrating at the rate of perhaps a million cycles a second. The apparatus for producing such currents is an **induction coil** or **transformer** (§ 234) or a **vacuum tube** (§ 238).

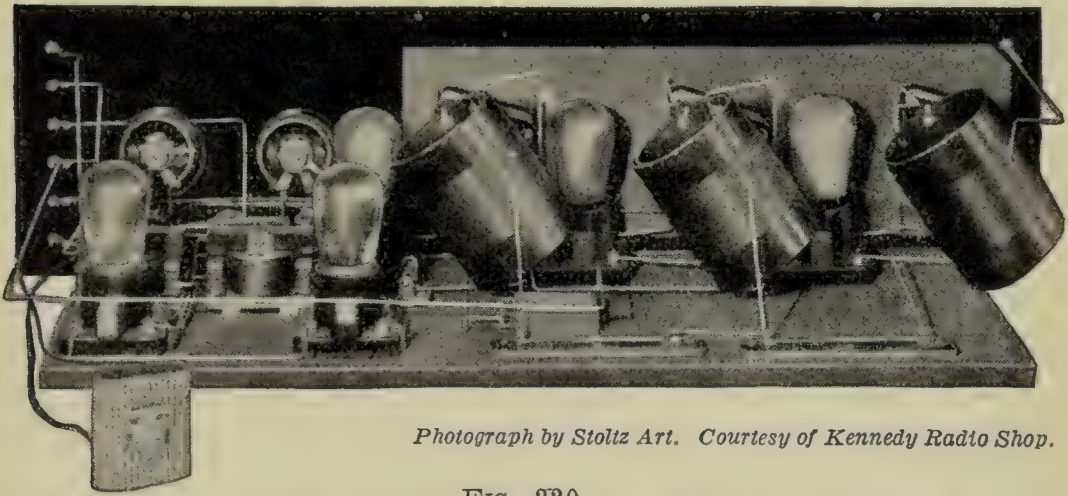
The rapidly oscillating current, however produced, rushes up and out to the end of the aerial wires one instant, and back to the ground the next instant. While the current is in the wires, it produces a **magnetic field** around them; when the current ceases, the magnetic field returns to the wires. But the formation of one magnetic field follows that of another at such a rapid rate that some of the electric energy escapes from the wires altogether, in the form of electric waves. The higher the frequency the greater the loss. These waves move out into space as water waves or sound waves move out from the disturbance that causes them.

The frequency of the electric waves that rush off the aerial wires is completely under the control of the operator in charge of the sending station; he can alter it as he wishes. Then the speakers and performers who are to do the *broadcasting* "go on the air," and add the effect of their sound waves to the electric waves that are being transmitted; or the key in a wireless-telegraph office clicks off its dot-and-dash message to some receiving station thousands of miles away.

231. Receiving the Waves.— It does not take a radio wave, moving with the speed of light, nearly so long to reach a receiving station on the opposite side of the earth, as it does for you to read this sentence. The receiving set must be able to pick up, or intercept, the radio waves that come from the transmitter. A wire loop, or an antenna, enables it to do this, provided the receiving apparatus is **tuned** to respond to waves of the same length and frequency as those that come to it. We can understand the need of tuning, if we think of what is called the "sympathetic vibration" of sounding bodies. Thus, if a given note is struck on a piano, a violin nearby often gives forth the same note. This is possible because the violin string is stretched just enough so that it can vibrate at the same frequency as the string struck on the piano.

The radio waves sent out from the aerial at the sending station are oscillating, high-frequency waves; they have the same qualities when they reach the receiving antenna, except that they are much weaker. Their alternations must be changed to direct current, and they must be "stepped-down," or lowered, in frequency to audio frequency, so that they can be heard in the receiving telephones. The apparatus by which these results are brought about is called the **detector.** The detector may be a crystal of **galena** (an ore of lead) or some other similar material (§ 236). For long-distance hearing the detector is usually a vacuum tube (§§ 238 and 239).

We can now let our fancy make a picture of the way in which sounds come to us by radio. We can say that the transmitter at the sending station picks up music or speech as waves of sound that move through air at the snail-like pace of only 1100 feet a second, and can never travel very far, and mounts them upon the back of swift electric waves travelling in all directions with the speed of light. In an instant they are at the receiving station. Then the receiving set allows the sound waves to dismount from their swift charger, to resume their usual pace, and to repeat to us the message or the music originally entrusted to them.



Photograph by Stoltz Art. Courtesy of Kennedy Radio Shop.

FIG. 220.

A five-tube assembled neutrodyne receiving set. The current from the antenna enters at the upper, right side. The A- and B-batteries are connected at the upper, left side. The C-battery is at the lower, left corner. The two vacuum tubes on the left are audio-frequency tubes, those on the right, in back, are radio-frequency tubes; the fifth one, left of the middle, in back, is the vacuum-tube detector. The three drum-shaped coils are air-core transformers, or neutroformers; back of them are three 13-plate condensers. Back of the two audio-frequency tubes are two rheostats and two transformers.

232. More Questions about Radio.— For some persons the explanation of radio given thus far is, perhaps, enough; but surely no one who is studying science will be satisfied until he gets a little better insight into the principles and apparatus that make radio sending and receiving possible. This will be true whether his knowledge of radio apparatus is confined to the turning of a few knobs, or consists of first-hand experience in the building of a receiving set. All of us want to know the answers to one or more questions like these:

How is a low-frequency current changed to one oscillating at the rate of a million cycles per second? How is a direct current changed to an alternating one, and an alternating current to one that is direct? How is a high-frequency current controlled, so that electric waves can be sent at any desired frequency and wave length? How are sound waves impressed on the electric waves in the broadcasting station? How is the receiving apparatus tuned, so that it will catch the radio waves from a particular station? How do induction coils and condensers work?

Before we go further into the details of radio apparatus let us learn a little more about matter and electricity.

233. The Nature of Matter and Electricity.— We have already learned that all bodies are believed to consist of tiny particles called **molecules** (§ 49). Scientists consider that molecules themselves consist of **atoms** (§ 103). The division of matter into particles does not, however, stop with molecules and atoms; for atoms, in their turn, are believed to give off still smaller particles, called

electrons. Electrons are electrically **charged.** They have **negative** charges: the kind we produce upon a stick of sealing wax or hard rubber, when we rub it with flannel or fur (§ 173). They are attracted by "positively" charged bodies and repelled by negatively charged ones. In fact, **electricity itself** is believed to consist of **electrons.** What we call an electric current is thought of today, by scientists, as a **stream** of electrons. Electrons travel readily along a conductor, but are held back by an insulator (§ 172).

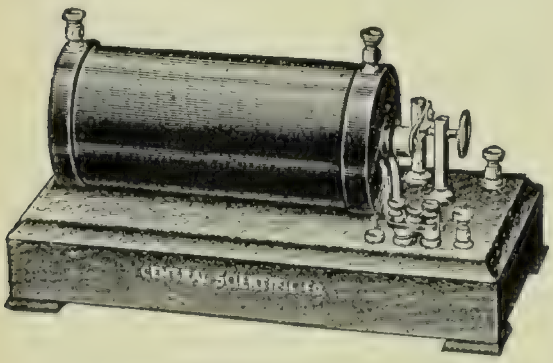
What happens when we rub a glass rod with a silk pad, as in § 172? According to the electron theory, **electrons** pass from the rubbed glass to the silk. The glass rod is said to be "positively" charged because it has lost so many electrons, which are negative. It needs to regain the lost electrons in order to be neutral once more.

The electron theory explains very nicely the way in which a charged body **induces** a charge in an uncharged, or neutral, body (see § 174 and Fig. 155). In the figure named, the positively charged rod attracts the negative charges (the electrons) toward that end of the egg shell which is nearest the rod. As a result the opposite end of the shell is short of electrons. We say that it is "positively" charged. If a negatively charged rod, such as one of sealing wax that has been rubbed with flannel, is brought near a neutral, or uncharged, shell, it will repel electrons to the opposite end of the shell, leaving the side nearest the rod positively charged.

"Stretch your mind," if necessary, in order to get an idea of what electrons are like; for you will need to know something of them to understand how a vacuum tube works (§ 238).

234. An Induction Coil.— We are now ready to learn how currents may be altered by induction coils and *transformers*. An induction coil is also called a **spark** coil (Fig. 221).

We have seen that a wire which is carrying a current has a magnetic field surrounding it (§ 181). We have also seen that if we move a wire, or a coil of wire, in a magnetic field, we get an **induced** current in the wire, or coil. The induced current is formed as the wire cuts across the lines of force of the magnetic field. The magneto and dynamo work according to this principle (§ 185). If we place one coil of insulated wire near another, and pass a current from a battery through one of the coils, there will be an induced current in the other coil, *as long as we keep one of the coils in motion.* We give the name **primary coil** to the one that carries the current from the battery; the one in which the current is induced we call the **secondary coil.** Generally, the primary coil is placed **inside** the secondary coil.


Courtesy of the Central Scientific Co.
FIG. 221.
Outside view of an induction coil.

There is another way of inducing a current in the secondary coil. Instead of moving one of the coils we can bring about a rapid "making" and "breaking" of the circuit in the primary coil. By so doing we cause lines of force to be formed, and then to disappear, a great many times every second. The result is the same as if we moved one of the coils. The device for producing the rapid making and breaking of the primary circuit is called a **vibrator,** or **interrupter.** We usually place a **core** of soft iron inside the primary coil, so as to strengthen the magnetic field, as in the case of an electromagnet (§ 182). Fig. 222 is a diagram of the parts of an induction coil and of the way in which the battery is connected with the primary coil and the interrupter. A **condenser** is also placed in the circuit, to store the electricity that accumulates, and so to increase the strength of the primary coil's magnetic field.

The **interrupter** of an induction coil works like the **armature** of an electric bell (§ 183). When there is a current in the primary coil, the iron core becomes a magnet and attracts the interrupter. As a result the circuit is broken, the core ceases to be a magnet, and the spring throws the interrupter back into place. The primary circuit is then complete once more. Every time the primary circuit is closed, or is broken, by the interrupter, a current is set up in the secondary coil. At "make" this current flows in one direction; at "break," in the opposite direction; hence it is an **alternating** current.

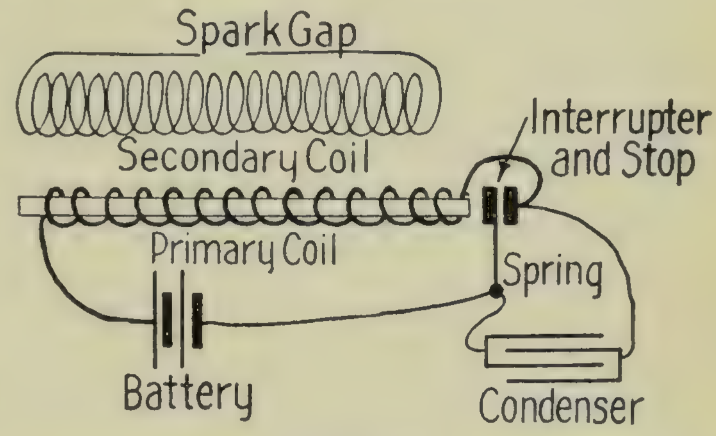


FIG. 222.
The parts of an induction coil. The primary coil (heavy wires) is placed inside the secondary coil.

The induction coil can also change the pressure, or **voltage,** and the frequency of a current. If the primary coil consists of only a few turns of large wire, while the secondary coil is made up of many turns of fine wire, then the induced current has a higher pressure and frequency than the primary current. We say that the current has been "stepped up." If we have a **gap** between the ends of the wires of the secondary coil, we can get large **sparks** across the gap. By the use of revolving mirrors investigators have found that the discharge which seems to be one electric spark is not a single flash, but a **series** of flashes that dash back and forth many times in an instant, too often, by far, to be distinguished from one another by the human eye. The sparks are to-and-fro (**oscillating**) discharges of the high-pressure electricity in the coil. In a single flash there may be 20 or 30 of these to-and-fro surges of the electric waves.

Transformers are instruments like induction coils, but without interrupters. They are either "step-up" or "step-down" transformers, according as they raise low-voltage currents to higher voltage, or the reverse. Transformers are used in radio apparatus, also in ordinary electric circuits. Thus, the current brought into our houses is usually carried along the outside, main-line wires at a pressure of about 2200 volts. Current at this pressure is dangerous in a house circuit, both because some one in the house might come in contact with a "live" wire, also because the "short circuiting" of such a current might cause the house to catch fire; hence the current is "stepped down" to 110 or 220 volts for use inside the house. Small transformers are used to "step down" the voltage still further, so that the current may be used to ring doorbells or operate electric toys. Induction coils may be used with either direct or alternating current; transformers only with alternating.

235. Sending by Wireless Telegraph.— If you understand the working of an induction coil, you will have little trouble with the diagram of a simple outfit for sending wireless telegraphic messages. In Fig. 223 you recognize at once the primary coil, with its few turns of heavy wire, and the secondary coil, with its many turns of finer wire. The interrupter is shown pressed back between the core of the primary coil and the stop. If you press the key for an instant, you make the primary circuit complete. The iron core then becomes a magnet, and draws the interrupter away from its stop. The instant you break the circuit, the core ceases to be a magnet, and the spring throws the interrupter back against its stop. By pressing the key for a shorter and then a longer time, the operator produces the dot and the dash of the Continental Code.

The induced current produced in the **secondary coil** collects until it has a high enough tension to leap across the spark gap as an oscillating discharge. The **condenser,** which is connected in the secondary circuit, stores the induced current, until a large amount has accumulated. When, finally, the discharge does take place, the spark is a large, "fat" one. The size of the condenser and the number of its plates determine how much capacity there is in the circuit. The number of plates in the condenser may be **fixed,** or **variable.** Attached to the aerial is a **coil** for changing the amount of **inductance.** The arrow-tipped wire represents a **sliding** connection, which can be moved by the operator. Much, or little, inductance may be used, according as the current passes through many, or few, turns of the aerial coil.

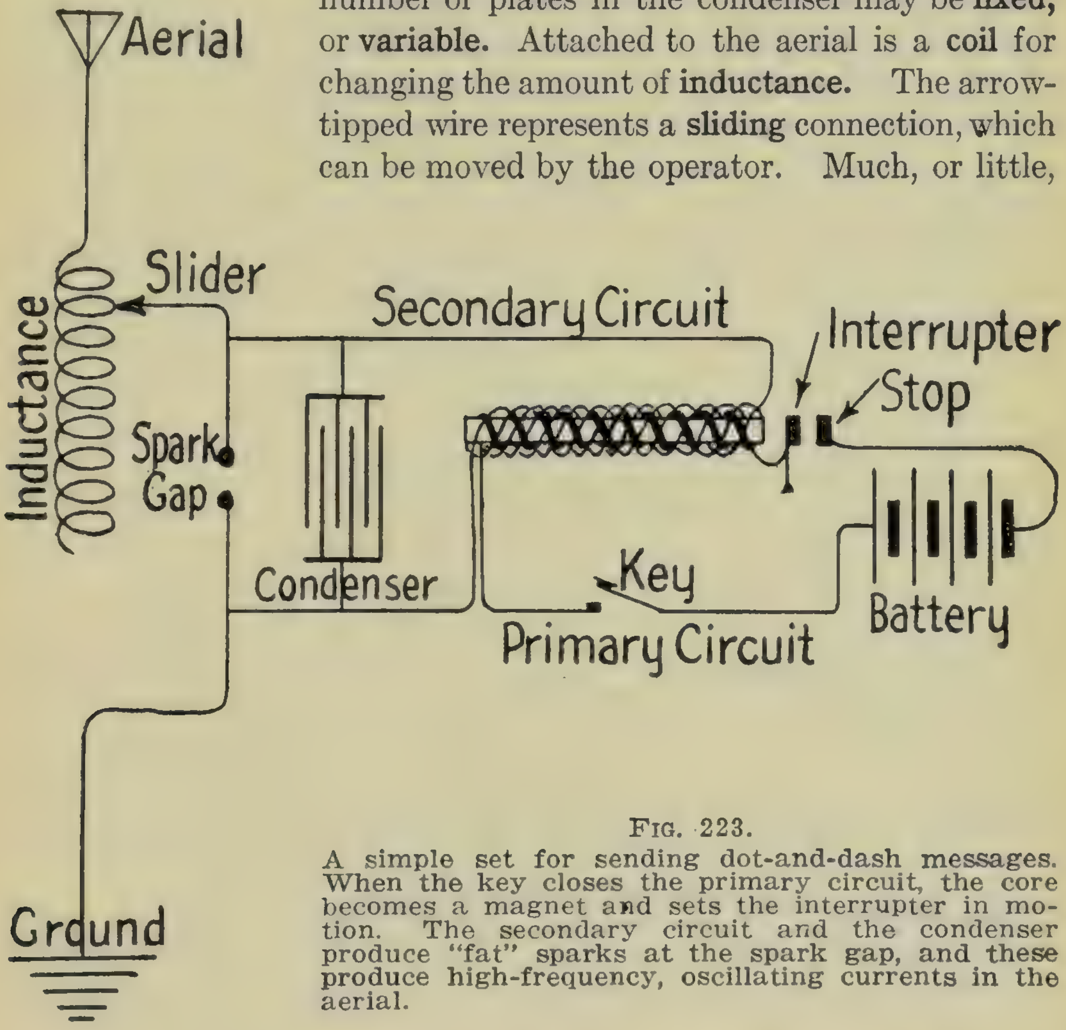


FIG. 223.
A simple set for sending dot-and-dash messages. When the key closes the primary circuit, the core becomes a magnet and sets the interrupter in motion. The secondary circuit and the condenser produce "fat" sparks at the spark gap, and these produce high-frequency, oscillating currents in the aerial.

The high-frequency electric waves are formed in the spark gap, the aerial and its coil, and in the ground connections. In order to change the wave length and frequency of the waves we change the **inductance,** or the **capacity**; that is, we change the number of turns of wire in the coil, or the number of plates in the condenser. If we add more turns of wire, we thereby decrease the frequency and increase the wave length; if we decrease the number of turns, we increase the frequency and shorten the wave length.

Wave lengths that may be used are regulated by **international agreement.** Amateurs are allowed to transmit only on wave lengths below 200 meters, and commercial companies on those of 300 to 600 and above 1600 meters. The government keeps wave lengths of 600 to 1600 meters for its own use.

236. A Simple Radio Receiver.

— The apparatus for sending messages by wireless telephone is somewhat more complicated than for the telegraph, and will be considered later (§ 240). However, a simple set for **receiving** messages is much the same for both; hence only one set will be described. At a short distance from a sending station wireless waves may be caught and changed into sounds by simple receiving apparatus; but at a greater distance the waves die out, and more sensitive instruments are needed.

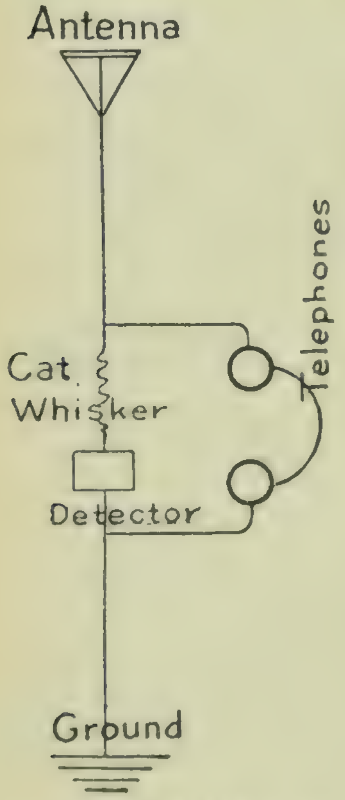


Fig. 224.
A simple receiving set. No tuning is possible with this arrangement. See Fig. 226.

About as simple an arrangement as can be thought of, for receiving wireless waves, is that shown in Fig. 224. It consists of an **antenna,** a **detector,** a pair of **telephone** receivers, and a **ground** connection. The antenna may be a single wire stretched between the house and the barn, or it may be a loop of wire kept in the house. Even

bedsprings have served as an antenna. The telephone receivers should have thin diaphragms and be as sensitive as possible, since the waves that come to the antenna are **weak.**

The **detector** is the apparatus for bringing the weak waves of high-frequency, alternating current down into the circuit containing the telephones, and modifying them so that sounds can be heard. One form of detector consists of a crystal of galena (§ 231) and of a wire that forms a loose contact with it. The wire is called a "cat whisker." Sometimes two crystals in loose contact form the detector. A successful detector does two things in the receiving circuit: (1) it converts the alternating current of the antenna into direct current, and (2) it lowers the frequency of the waves to **audio frequency** (§ 229).

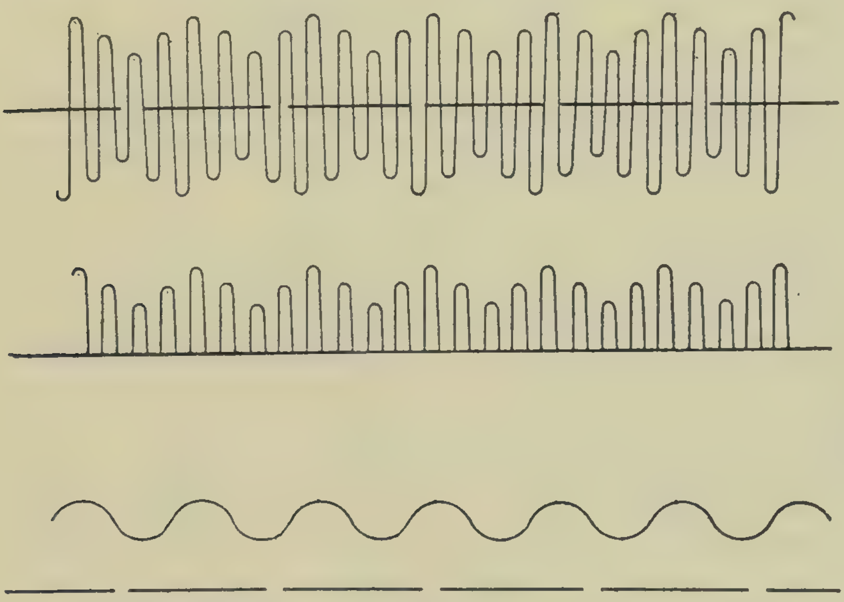


Fig. 225.

What the detector does when it demodulates a radio wave train. The current becomes direct, and the frequency is lowered to audio frequency.

How does the crystal detector change alternating current into direct current? We have seen that an alternating current is one that changes its direction every instant. Crystals of galena and of some other materials allow a current to go through in one direction, but not in the reverse direction. Therefore, only half of an alternating current goes through the crystal detector, and this half is now a direct current. The frequency of the current is also decreased, so that the sound waves that were impressed upon it by the sending instrument, can now reappear in the telephones. The dots and dashes of the telegraph code are heard as short and long buzzes, or other sounds, in the receiver. Fig 225 shows the effect of the detector upon an alternating radio current.

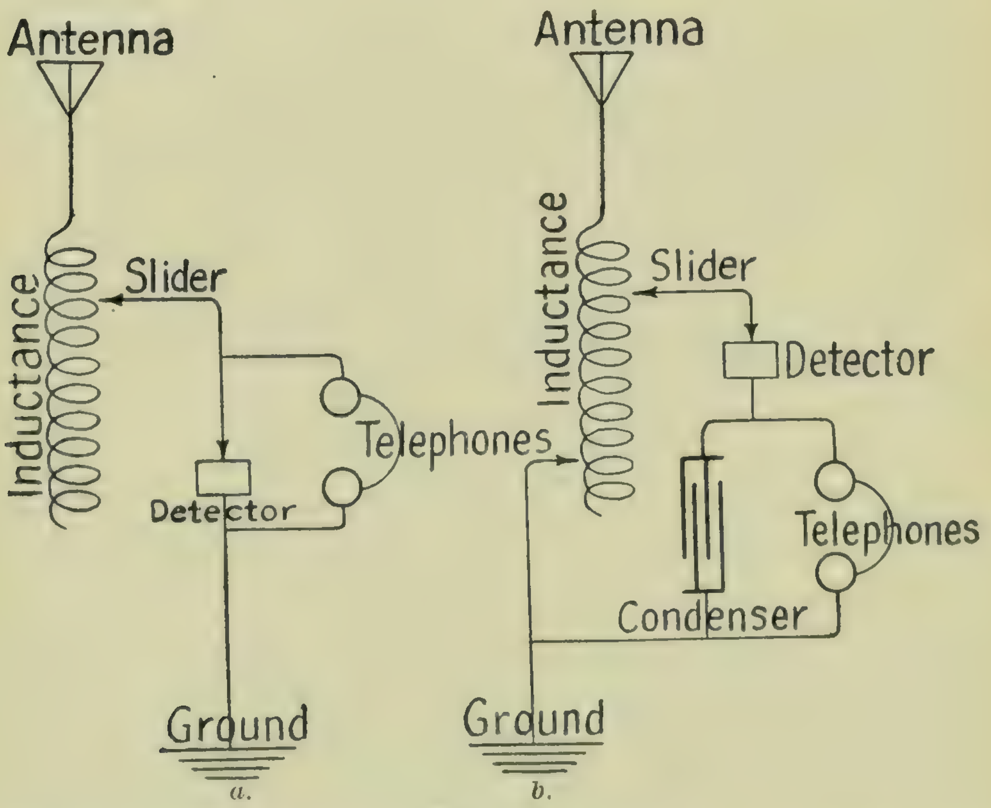


FIG. 226.

a and *b*. Diagrams of two more receiving sets. In *a*, a tuning coil has been added, so that the inductance may be changed; in *b*, a condenser, as well as a tuning coil, has been inserted.

237. Tuning.— In the last section (Fig. 224) we studied the simplest possible arrangement for a receiving set. Fig. 226, *a* and *b*, shows two arrangements with additional parts to make the receivers more successful. Fig.

226, *a*, for example, has exactly the same parts and arrangement as Fig. 224, except that a coil has been added to the antenna. The arrow-tipped wire touching the coil represents, as usual, a sliding contact. If the operator wants the current from the antenna to flow through more turns of wire, he pushes the slider downward; if he wants less, he slides it upward. By thus altering the inductance (see § 235) he adjusts the receiving apparatus to the wave length of the radio waves he wishes to "pick up." In the arrangement shown in Fig. 224 this is not possible.

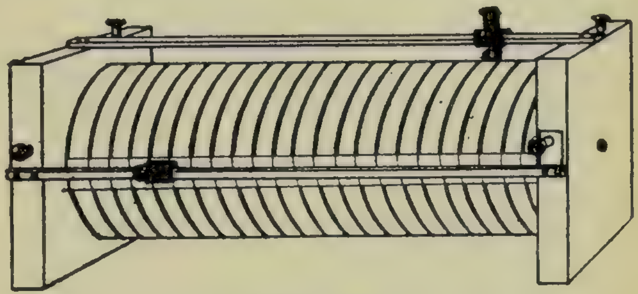


FIG. 227.
A two-slide tuning coil. The insulation is removed from the coil along two lines, so that the slider can make contact with each turn of wire.

Fig. 226, *b*, shows a second addition to the simple set. It has now not only a coil but also a **condenser.** The **oblique** arrow shows that the condenser is a **variable** one; the number of its plates can be changed, and in this way the **capacity** of the circuit can be changed. The process of changing the inductance of the coil and the capacity of the condenser of a receiving set, so that the set can pick up waves of any desired wave length, is called **tuning.** We control the wave length at the sending station in the same way (see § 235). An inductance coil is also called a **tuning** coil (Fig. 227).

238. The Vacuum Tube.— The induction coil and condenser have been known for a long time, and by making use of the principles according to which they work men were able to do much in the development of radio communication. But for the wonderful growth of modern radio we are indebted to the **vacuum tube.**

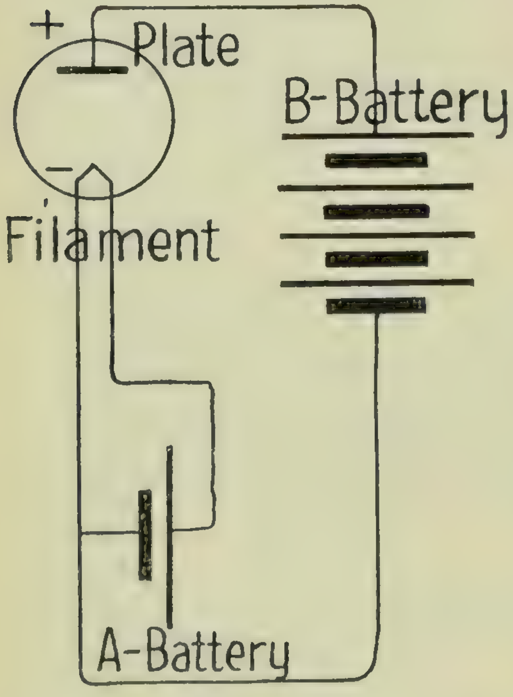


Fig. 228.
A two-electrode vacuum tube, or electric valve. The battery that heats the filament is called the filament battery, or A-battery; the one that passes current from the filament to the plate is called the plate battery, or B-battery.

A vacuum tube looks very much like an ordinary incandescent bulb (Fig. 228). In its simplest form it contains a **filament** to be heated and a second wire or piece of metal called the **plate.** It was Edison who first observed that while the filament is cold no current can be sent across the gap between the filament and the plate; but if the filament is first heated, a current can be made to flow through the empty space without the presence of any visible conductor. This is a strange fact; but one equally strange is that a current can be made to flow through the tube in only **one** direction: from the filament to the plate, but not from the plate to the filament.

Our modern view of electricity and matter "explains" the tube's behavior. When the filament is heated to white heat, the electrons of its atoms are thrown into violent motion, and are therefore held less firmly than when the filament is cold. If we connect the plate of the vacuum tube with the positive (+) pole of a battery, and the filament with the negative (—) pole, electrons are attracted from the filament to the plate. If, however, the plate is made negative, the electrons will not be attracted, but repelled. The current flows from the hot filament to the plate upon a "bridge" of electrons.

We are now ready to understand how a vacuum tube affects an alternating current. At one instant such a current makes the plate positive; at the next instant, negative. Hence if we try to pass an alternating current through the vacuum tube, only the part that goes from filament to plate gets through, while the part going in the opposite direction cannot. As a result, the vacuum tube changes an alternating current to a direct one, just as the crystal detector does. A vacuum tube is also called an **electric valve**; why? A vacuum tube containing only a filament and a plate is called a **two-electrode,** or **two-element,** tube, or valve.

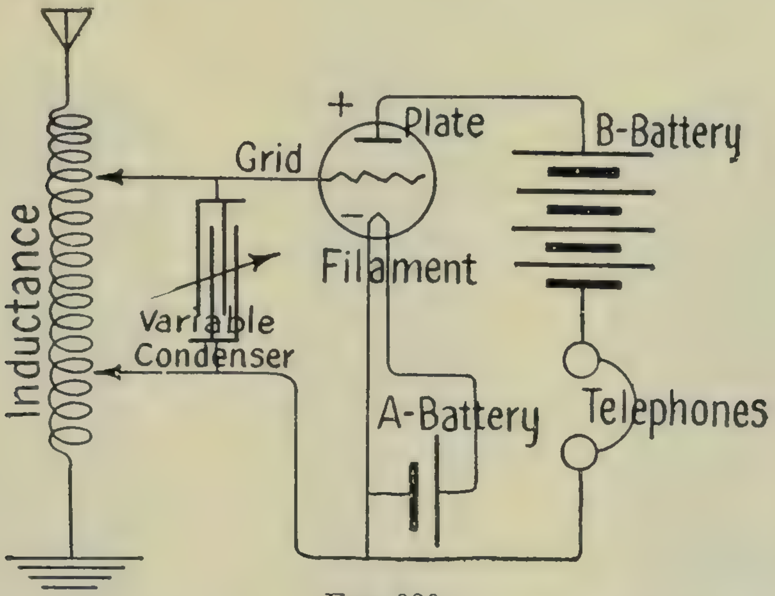
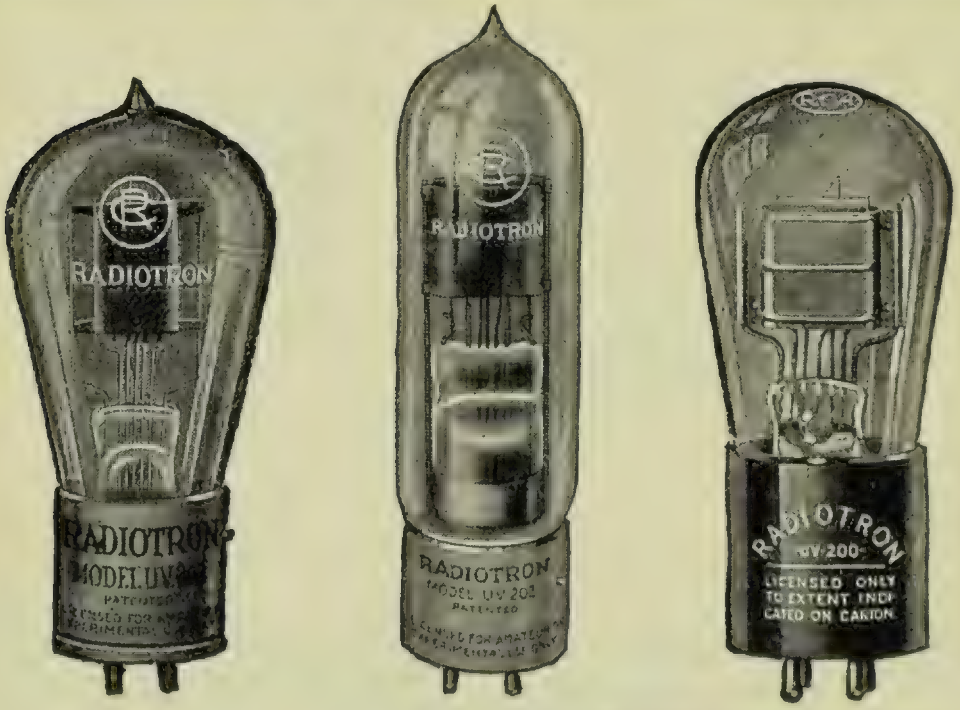


FIG. 229.

A three-electrode vacuum tube. It is the tube of Fig. 228 with the addition of a grid and the necessary connections for the detection of radio waves. Note the telephones in the plate-battery circuit and the variable condenser in the grid circuit.

239. Tubes with Three Electrodes.— The vacuum tube commonly used in radio sets is a three-electrode tube (Figs. 229 and 230). It has a filament and a plate, like the simpler tube, but it has also a **grid,** consisting of a network of parallel or latticed wires.

As Fig. 229 shows, the A-battery is connected so as to let current pass through the filament. The direct current from the plate battery (B-battery) forms a second circuit. Its negative electrode is the filament; its positive electrode is the plate. The **grid** forms one electrode of a **third** circuit; the other electrode of this circuit is the plate. In a receiving set this third circuit carries the induced, alternating currents from the antenna, with the sound waves impressed upon them.



Courtesy of the Radio Corporation of America.

FIG. 230.
Types of three-electrode vacuum tubes.

When there is no electric charge in the grid, the direct current of the B-battery flows through the filament and plate unchanged, on the "bridge" of electrons. But when an alternating current enters the circuit containing the grid, the grid produces very important effects upon the direct current. For the instant during which the grid is positive (+), it assists the plate in attracting electrons from the hot filament, and thus allows a stronger current to flow through the tube. The next instant the grid is negative (—); it then retards the passage of electrons, and weakens the direct current. Thus every variation in the alternating current, due to the sound waves that were impressed upon it in the sending apparatus, is reproduced in the vacuum tube of the receiver, and in the telephones which we place in the plate circuit.

The direct current of the plate battery not only takes up the alternating waves with their impressed sound waves, but it **strengthens** them, so that they can be heard more readily. It thus acts as an **amplifier.** What does "amplify" mean? We can understand this effect, if we review what we learned in § 226 about the transmitter of our modern telephone. The primary circuit of the telephone strengthens the weak induced currents produced by the diaphragm, because it adds its own energy to them. In the same way the vacuum-tube detector strengthens the feeble waves that come from the receiving antenna, because it adds to them the energy of the B-battery. The vacuum tube therefore detects waves from a much greater distance than the crystal detector.

Often a **C-battery,** of low voltage, is used to keep the grid **negative,** or to give it a negative **bias.** It is connected between the filament and the grid (see Fig. 220).

240. Broadcasting.— What interests people most in radio communication is probably the receiving of programs from broadcasting stations. The studio, or room, from which radio programs are sent, is now planned with the greatest care, so that the sound waves to be transmitted may not be injured by some fault in the construction or furnishing of the room. The actual **operating room** of a station may be some distance from the studio (see Frontispiece). The human voice is a weak instrument, and it must be built up enormously in order that it may be carried by wireless. The operation of impressing the sound waves of the voice upon the high-frequency current is called **modulation,** and a vacuum tube used for this purpose is called a **modulator.**

The performer speaks or sings or plays before a **microphone** and sets its diaphragm in vibration. The microphone (what is its literal meaning?) is a telephone transmitter built for a strong current. The impressed sound waves are carried by the current to the grid of a vacuum tube (modulator) much as similar waves produced by the telephone transmitter are carried to the main line by means of the current of the local battery. These incoming currents produce variations in the current passing through the vacuum tube. At the same time the currents are strengthened by the energy they receive from the B-battery, or other source of electricity. The strengthened currents are then run into another vacuum tube, more powerful than the one before it. This operation is kept up until the currents have been sufficiently strengthened; then they are run into the aerial.

What is the future of radio communication? Will it be developed to such an extent that it will take the place of the wire telegraph and telephone, or will it be only an **addition** to these as a method of communication? Will the people of the future get their speeches, music, perhaps even their lessons, at home, by radio, or will they continue to go to halls and schools for the purpose? Some of you who are now studying this book may have a large share in determining the answer.

241. Summary.— **Sound** is due to the **vibration** of bodies. It travels through air, as well as through other gases, and through liquids and solids.

Sound waves are longitudinal: the vibrating particles move forward and backward a **very short** distance, in the same direction as the wave motion.

Waves have **length** and **frequency.**

Echoes are reflected sound waves.

Tone is due to the **regular** vibration of the sounding body; **noise** is due to irregular vibrations.

Pitch depends upon the **frequency** of vibrations.

Musical instruments may be **stringed** instruments or **wind** instruments, or vibrating **masses** or **disks.**

In **making** a **phonograph** record we change sound waves into wavy lines on the record; in **using** the record we change the wavy lines back into sound waves.

In the simple **telephone** the vibrations of an iron diaphragm in the field of **one** magnet produce corresponding vibrations in another diaphragm placed in the field of a **second** magnet, some distance away.

The **modern telephone** is built upon the additional principle that the feeble currents induced by the vibrating diaphragm can be **strengthened** by a local current, so that messages can be carried to a greater distance.

Wireless waves belong in the class of electromagnetic waves, along with those of heat and light.

A **sound wave** is **impressed** upon a train of electric waves, and modifies, or **modulates,** them.

High-frequency, oscillating waves or currents are produced from ordinary currents by induction coils, transformers, or vacuum tubes.

Radio waves are brought into a receiving set by means of a **detector,** which changes the waves to **audio frequency.** Detection is also called **demodulation.**

Electricity is believed to consist of **electrons.**

An **induction coil** with a **spark gap** changes low-frequency, direct current to high-frequency, oscillating current.

Tuning consists in changing the **inductance** of a circuit, or its **capacity,** so that the radio set can respond to waves of any desired length.

A two-electrode **vacuum tube** changes alternating to direct current.

A **three-electrode** tube is used in a receiving set as a **detector.** In its various forms it can change current from alternating to direct and direct to alternating; from low frequency to high frequency, and high frequency to low. It can build up feeble current for transmission, and **amplify** the weak waves caught by the detector. Modern radio work depends upon it.

Broadcasting has become a fine art.

242. Exercises.— 1. A circular saw gives forth a high note when it is revolving; but the pitch of the sound falls when the saw cuts into a board. Can you suggest why?

2. When a hall is full of people, its echoes often disappear. Why?

3. Why is it harder for a speaker to be heard in the open air than in a hall?

4. Why can you not make a noise by waving your arms around in the air?

5. From the fact that you can hear the buzzing of a fly, what do you conclude as to the frequency of vibration of its wings?

6. The echo of an explosion is heard 6 seconds after the explosion. About how far has the sound travelled in the meantime? How far away is the reflecting surface?

7. Give the stages by which the grooves upon phonograph records are changed to words or music.

8. How are sound waves carried through a speaking tube?

9. Why ought you to be able to hear a distant truck or wagon better by putting your ear to the ground?

10. What are the advantages of hearing a famous singer or speaker by radiophone? Are there any disadvantages?

11. What is the greatest disadvantage of seeing plays only in motion pictures? What are the advantages?

12. Tell the story of the way in which a wireless telephone message is sent and then received.

243. Projects.— 1. Construct a simple string, or wire, telephone, and show the class how it works.

2. Demonstrate to the class the construction of a phonograph reproducer and record (§219).

3. Calculate about how long the spiral groove of a phonograph record is, and report your results to the class. Assume that the circumference is $3\frac{1}{7}$ times the diameter.

4. Set up some apparatus to demonstrate the sympathetic vibrations of musical notes. Consult a textbook of physics.

5. Prepare a report upon those peculiarities of construction and material which give a violin its special "quality." Consult a violinist.

6. Prepare a report on the causes that produce the special qualities of the human voice. Consult an instructor of vocal music.

7. Study the construction of a set of chimes in your neighborhood, and report the results.

8. Demonstrate to the class the construction and operation of a xylophone, a triangle, and a flute.

9. Demonstrate the construction of the "loud speaker" of a radio set.

10. Demonstrate to the class some piece of apparatus used to assist persons who are hard of hearing.

11. Consult an architect regarding the rules to be observed in the construction of a hall, so that there shall be no disturbing echoes, also regarding the cure for such echoes where they exist. Report the results to the class.

12. Prepare a report on the life of Alexander Graham Bell, and tell how he became interested in the transmission of sounds.

13. Prepare a report on what Marconi, Armstrong, and De Forest have had to do with the development of radio communication.

14. Demonstrate the fact that a sounding tuning fork is in vibration. Use some method besides that of Fig. 210.

15. Determine if a vacuum cleaner gives off a musical note while running. Determine also if the pitch changes as the cleaner has harder, or easier, work to do; also when power is turned on or off. Report the results, and explain them.

16. Devise some way of determining whether a ringing bell can

be heard farther "against" the wind, or "with" the wind, and report the results.

17. By the use of a microscope or a powerful magnifying glass show the class the difference between the point of a phonograph needle that has been used several times and one that is new.

18. Demonstrate to the class the way in which a crystal detector, a spark coil, and a condenser work.

19. By means of a radio set explain to the class the use of a tuning coil, a three-electrode vacuum tube, and an amplifier.

20. Show the class some of the apparatus by means of which the current needed for the plate circuit (B-battery) is obtained from the lighting current of the house.

21. Prepare a paper on the place of the radiophone in man's systems of communication.

244. References.—BAKER: *Boy's Book of Inventions.* KENDALL AND KOEHLER: *Radio Simplified.* LESCARBOURA: *Radio for Everybody.* MACFARLANE: *The Phonograph Book.* MILLIKAN AND GALE: *A First Course in Physics.* TOWER, SMITH, TURTON, AND COPE: *Physics.* VERRILL: *Harper's Wireless Book.*

CHAPTER XIV

ACIDS, ALKALIES, AND CLEANING

245. Materials of the Household.— For some time we have been thinking of the forces of nature which we bring into our houses and schools. We have studied about electricity and electric appliances; about light and the ways in which we use it; about sound and how it carries our messages. In Chapter XIV we are to learn about some of the materials that the chemist calls acids and alkalies and how we use them in the important household operations of washing and cleaning. In Project 5, § 5, you were asked to make a list of the different substances used in your kitchen and laundry. This is a good time for you to review that list or to make a new one. Classify the substances into those used: (1) in washing and cleaning; (2) in cooking or otherwise preparing our food. Some may be found in both lists.

246. What are Acids?— The word "acid" means **sour** or **sharp,** or **tart.** The juices of ripe fruits are sweet because they contain a "sugar"; but when they are allowed to stand in the air, they "work," or **ferment** (§ 64). They give off bubbles of carbon dioxide and become "hard." The "hardness" is due to *alcohol.* Thus sweet cider becomes "hard" cider, and grape juice becomes wine. This "alcoholic fermentation" of the sugar of fruit juices is caused by **yeast,** or, better, by a peculiar substance (**ferment**) present in the yeast.

The change of the fruit juices does not stop here. When the fermented juices, which now contain alcohol, stand longer in the air (Fig. 231), another kind of fermentation takes place, and they become **sour.** We then call them "vinegars." Thus we get cider vinegar from apple juice and wine vinegar from grape juice. The cause of this second fermentation is a plant called the "vinegar mold," or "mother of vinegar." The sourness of vinegar is due to **acetic** (a-sēt′ic) **acid.** Vinegar has usually only about 3% to 5% of it.

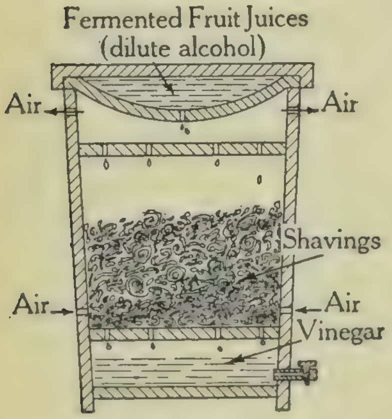


FIG. 231.
Quick vinegar process. The air oxidizes the fermented fruit juice, and changes its alcohol to acetic acid.

Other fermentations take place besides those that give acetic acid. Thus "dill" pickles are small cucumbers fermented so as to give lactic, or "milk," **acid; sauerkraut is** cabbage which has been partly changed into the same acid. Sweet **milk** becomes sour because its "milk sugar" is changed into lactic acid. All acids contain **hydrogen.**

Many **plants** contain acids. This is true of the stems of rhubarb and sour grass and of fruits such as tomatoes, cherries, and apples. Lemons, oranges, and grapefruit contain **citric acid**; grape juice contains **tartaric** acid; apples contain **malic** acid.

Some acids are manufactured on a large scale. Such are **sulphuric** acid, which the chemist represents by the *formula:* H_2SO_4; **nitric** acid (HNO_3); and **hydrochloric,** or *muriatic,* acid (HCl). Of what elements is each of these composed? See Appendix X. Hydrochloric acid is present in the **gastric juice** of man and of many animals. Carbon dioxide, dissolved in water, forms **carbonic acid** (§ 62).

247. What Acids are Like.—Thus far we have thought of acids only as sour substances; but what distinguishes them even more than their taste is their great **activity.** They act upon many other materials. Thus they change natural colors such as those of purple cabbage and of litmus. In fact, a substance that changes blue litmus to red is said to have an **acid reaction.** Acids often change the coloring materials with which our clothing is dyed. Thus dilute hydrochloric or sulphuric acid changes "navy blue" to red.

The most active acids readily "eat," or destroy, the skin and clothing on which they fall, and must be washed off at once. They also "eat," or "corrode," or "etch," metals. We have already learned (§ 100) that when hydrogen is prepared by the action of an acid with zinc, the metal is used up. Iron, aluminum, and tin act in the same way. Copper and lead cannot be used for cooking utensils, because they react with the oxygen of the air, and then with the acids of fruits and other food, producing poisonous compounds (see § 95).

Acids also react with marble, limestone, washing soda and baking soda. These all belong to the class of substances called **carbonates;** they bubble, or effervesce, even with very dilute acids, producing **carbon dioxide** (§ 61). The limestone of bones, oyster and clam shells, and of coral is rapidly eaten out by acids, and only the animal material is left. Bones and shells therefore lose their stiffening when placed in acids. The large amount of acid in a dog's stomach permits him to digest bone.

248. What is a Base?—We do not hear the words "bases" and "alkalies" so often as "acids," but we use basic materials commonly enough, under the name of **lye.** Ammonia water and slaked lime also belong to the class of bases, or alkalies.

You probably know how hard it is to wash a greasy dish with water alone, because the grease, or fat, does not dissolve in the water. But if you add a little lye to the water, the grease disappears. We say that the lye "cuts" the grease. What happens is that the lye solution acts with the grease to form new substances that dissolve in water. One of these new substances is a soap (see § 251). If we wish to use a **mild** base, as for the purpose of cutting the grease on windows or glassware, we often use ammonia water.

We give lye the name **sodium hydroxide,** to show that it is composed of sodium, hydrogen, and oxygen. **Potash lye** is **potassium hydroxide.** Of what elements is it made up? The chemical name for ammonia water is **ammonium hydroxide,** and for slaked lime, **calcium hydroxide.** Washing soda acts like a base, but sodium hydroxide is much more active, and destroys the skin much as a hot body would. Hence sodium hydroxide is called "caustic," or burning, soda.

Lime is our cheapest base. Men make it on a large scale by heating limestone in a furnace called a **lime kiln.** The high temperature causes the limestone to break up into lime and carbon dioxide. What becomes of the carbon dioxide? The lime obtained is called "quicklime." It unites with water very greedily to form slaked lime. When masons put lumps of quicklime into vats of water, the water becomes almost boiling hot. **Mortar** is the pasty mass formed when sand is mixed with slaked lime and water. Slaked lime dissolves to a small extent in water, forming **limewater.** This can be added to slightly soured milk to sweeten it. A mixture of olive oil and limewater is used to heal burns.

A dilute solution of a strong base like lye has a **bitter** taste; a concentrated solution of it must not be put into the mouth, or the mucous membrane that lines the mouth will be destroyed.

249. How an Acid Acts with a Base.— We have not yet learned how we can distinguish a base from an acid, except by *taste.* The common way is to use **litmus** (§ 247). Litmus is a colored material obtained from certain plants called *lichens* (lī′kĕns). An acid (in solution) turns blue litmus **red.** The solution of a base changes red litmus to **blue.** A substance which does this is said to have a **basic reaction.** What is an *acid* reaction? We may use the litmus in the form of a solution, and put a few drops of the solution into the liquid we are testing, or we may use *litmus paper*, and dip a strip of it into the liquid. We may use *purple cabbage* solution in place of litmus.

There is another way in which the solution of a strong base, such as caustic lye, differs from the solution of an acid: the basic solution feels slippery, or slimy, when we rub it between our fingers, just as though we were using a concentrated soap solution. Try this.

We are now ready to consider what happens to the properties of a base when we add an acid to the base. If to some sodium hydroxide solution (caustic soda) we add a strip of litmus paper and then, drop by drop, a dilute solution of some acid, such as sulphuric or hydrochloric acid, and stir the solution thoroughly after the addition of each drop of acid, we shall find that the litmus finally turns red. If we are very careful, we may be able to stop when the litmus has a *lavender* color, between blue and red. The solution no longer has a slimy feeling, and has no marked effect upon either kind of litmus. We say that the acid has **neutralized** the base. In the same way a base can neutralize the properties of an acid. The solution now has a **neutral** reaction, neither acid nor basic.

If we neutralize a solution of sodium hydroxide carefully with dilute hydrochloric acid, and evaporate the water slowly, we obtain cubical crystals of **common salt** (§ 97). When sulphuric acid is used, the substance obtained is not common salt, but one that resembles it in some ways. We call all such substances **salts,** because, like common salt, they may be prepared by the neutralization of a base by an acid.

There are many salts. Limestone, blue vitriol, sal ammoniac (see § 179), saltpeter, and alum, as well as table salt and many others, belong to this class.

Courtesy of the Amoskeag Manufacturing Co.

FIG. 232.
Picking cotton on a Southern plantation.

250. The Materials of Clothing.— We use **four** common fibers for clothing and household fabrics: cotton, linen, wool, and silk (Fig. 232). Cotton and linen are **vegetable** fibers, and consist chiefly of **cellulose,** a substance which in its composition resembles sugar and starch (§ 66), but is insoluble in water. Cotton is the downy covering of the seeds of the cotton plant; linen is found in the stalks of flax.

Both cotton and linen consist of long, hollow tubes; but the fibers of cotton are flat and twisted, while those of linen are nearly straight, with thick walls and a central opening. Linen cloth is stronger than cotton, but cotton is lighter and more elastic.

Cotton and linen are easily destroyed by such acids as sulphuric and hydrochloric acids, if these are concentrated, or if the dilute acids are allowed to dry upon the fabrics. They are not so easily harmed by alkalies. In fact, if cotton is treated for a short time with a strong base, and is then washed thoroughly, it is actually made stronger, and has a glossy, silky appearance. Cotton so treated is called **mercerized** cotton.

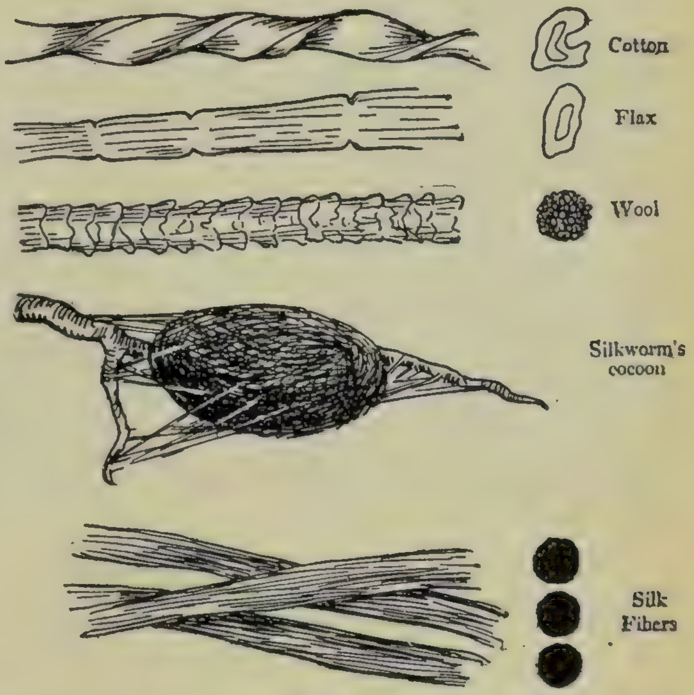


FIG. 233.
The fibers of cotton, flax, wool, and silk, and a silkworm's cocoon. Note the structure of wool, with its overlapping scales.

Wool and silk are of **animal** origin. What is the source of each? They are opposites of cotton and linen in behavior with acids and alkalies; for they are not readily acted upon by acids, but are easily destroyed by alkalies. The fibers of wool are also entirely different in **structure** from those of linen and cotton. Instead of *long* cells, wool has *short, thick* cells,with the projecting edges of each cell overlapping part of the cell next to it (Fig. 233). The surface thus seems to be covered with horny scales all lying in one direction. Woolen fabrics need to be washed with great care, or the cells will be forced together, and the wool will shrink, until finally it becomes stiff and board-like.

Dyes.— Dyes are colored substances that are either absorbed by the pores of a fiber, or combine with the fiber to form a colored, insoluble compound. What are "fast" colors? Silk and wool can combine directly with many more dyes than cotton and linen can. We can think of the process of dyeing cloth as partly a **chemical change** (§ 103), much like that which takes place when an acid and a base react to form a salt (§ 249). The dyed fabric corresponds to the salt.

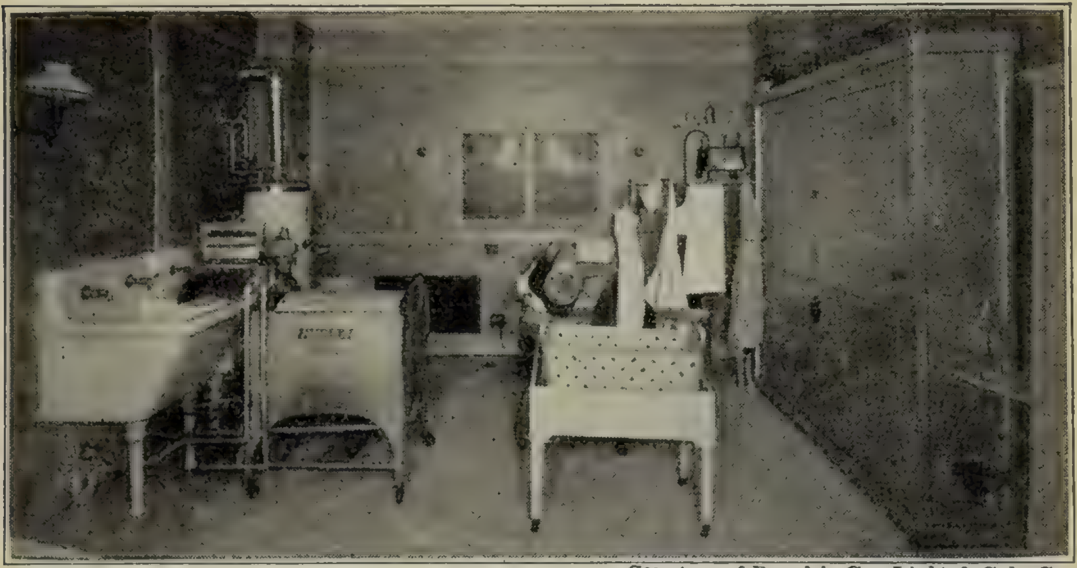
The cellulose of cotton and linen combines with very few dyes **directly**; hence a **third** substance, called a **mordant**, is generally used. This combines with the fiber on the one hand, and with the dye on the other, and holds the two together.

251. The Washing of Clothing.— Now that we know something of the ways in which acids and bases act, we can study one of the common operations of the household: the washing of clothing (Fig. 234). Clothing that has been worn too long has a damp, sticky feeling, because its pores are clogged with materials given off by the skin. These consist of perspiration, of waste materials which the body casts off through the skin, and of dead skin itself. When such materials fill the pores of the clothing, it is unfit for us to wear, whether it looks dirty, or not. The perspiration, by its evaporation, regulates the temperature of the body (§ 54), and our clothing should help, not hinder, this evaporation. Clean garments feel so comfortable largely because they have a fresh, absorbing surface.

We therefore wash clothing for **three** reasons:

(1) In order to remove dirt and open the pores of the clothing.

(2) In order to dry the washed clothing and give it a fresh absorbing surface.



Courtesy of People's Gas Light & Coke Co.

FIG. 234.

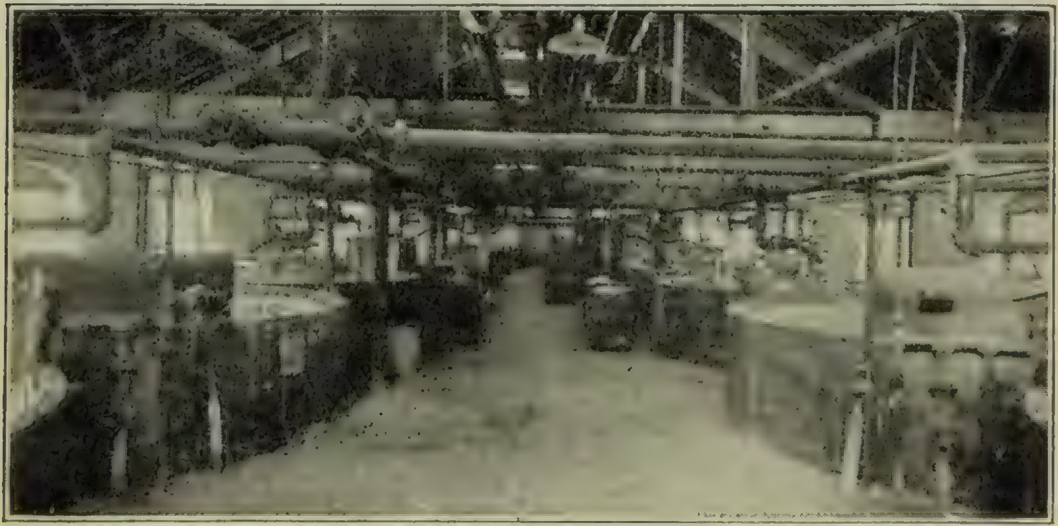
Modern home-laundry equipment, showing a rotary electric washer, its water kept hot by a gas jet underneath. Middle of page, a basket-table on casters; behind it an electric ironer. On right wall a gas-heated drying closet.

(3) In order to destroy the bacteria that accumulate in the dirt of the skin and clothing.

We should have clean bodies for the same reasons that we should wear clean clothing, if for no others: in order that the pores of the skin may be permitted to act freely in removing waste materials; and in order that the perspiration may evaporate readily.

252. How Soap is Made.— In order to remove dirt we need not only water, but **soap.** The common method of making soap has already been suggested in § 248: the "cutting" of a fat by a strong base, such as caustic soda (Fig. 235). When the two are heated together, the fat goes into solution. The substances formed are the **sodium salt** of a complex acid, and **glycerine.** The sodium salt is the soap. When salt is added to the solution, the soap is "salted out," and floats on top. It is then skimmed off, pressed and dried, and cut into cakes.

In some soap factories the fat is first heated with steam; glycerine and a complex acid are formed. Soap is then prepared by the **neutralization** of the complex acid with soda. Glycerine is a valuable "by-product" of soap making. For what is glycerine used?



Courtesy of Procter & Gamble Co.

FIG. 235.

Modern way of making soap. The kettles are three stories high, and each kettle holds 250,000 to 300,000 pounds of soap.

Not so very many decades ago soap was still made, partly, at least, in the household (Fig. 236). In the spring the winter's accumulation of wood ashes was pounded down into a barrel, and set on a sloping platform to be "leached," or extracted, with water. A hole was made in the ashes, water was poured in, and the solution of **potash** (potassium carbonate) that was formed trickled out into little troughs in the platform. The solution was collected in a kettle and boiled down (evaporated) to form the home-made **potash.**

The winter's accumulation of fat and grease was also saved for soap. A kettle of fat was melted over an open fire, the lye was added to the fat, and the two were cooked together, often for two or three days. The resulting "soft soap" was stored in barrels for the next year's use.

Modern soaps are made not only from animal fats, such as beef suet, mutton tallow, and lard, but also from vegetable oils, such as olive oil, palm oil, cocoanut oil, and cotton-seed oil. Oils are **liquid fats.**

253. How Soap Acts in Cleansing.— The dirt that we want to remove from clothing by means of soap is generally some form of grease, or soot, or earthy material. When the soap solution is rubbed upon greasy cloth, it breaks up the grease into minute **droplets** and surrounds them. Thus they are separated from the cloth and from one another and can be washed away by the water. Water by itself has not this power.

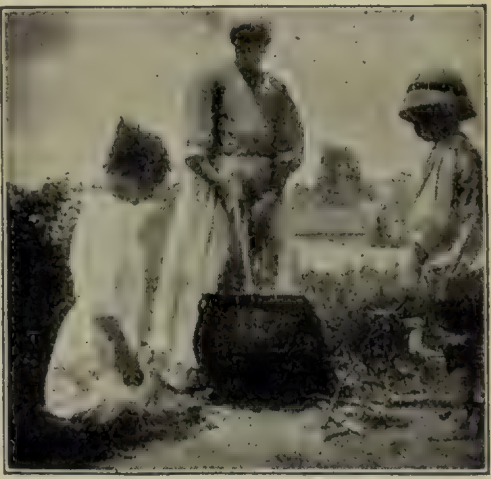


FIG. 236.
The old way of making soap from grease and potash.

It is easier for us to understand this power of soap solution to break oily liquids into tiny droplets, if we see the effect of soap solution upon *kerosene*. If you put a little kerosene upon some water in a test tube or small-mouth bottle, and shake the two together vigorously, the kerosene breaks up into droplets; but when you stop shaking, the droplets unite again, and the layer of kerosene floats upon the water. But if you use a dilute soap solution in place of the water, the kerosene does not separate easily into a layer by itself; it remains in the form of droplets scattered through the soapy water. We call a mixture like this an **emulsion.** **Milk** is an emulsion made up of particles of butter fat suspended in the watery portion of the milk.

When a soap solution is rubbed upon sooty or earthy material, the soap solution surrounds the tiny, solid particles, so that they can be washed off by water. **Soap bark,** obtained from certain trees, has a power similar to that of soap.

Hard water is very disagreeable to use for bathing, or for washing clothing (see § 92), because it contains salts (generally calcium salts) which react with the soap to produce an insoluble scum before suds can be formed. The scum is a **calcium soap,** which gets into fabrics and injures them.

254. Cleansing without Soap.— In some methods of cleansing fabrics, soap and water are not used. This is true of **dry cleaning,** or washing by means of gasoline or some similar solvent. Dry cleaning is used especially for silks and woolens, which lose their soft finish if washed often in water. The gasoline evaporates rapidly from the material, leaving it clean and soft as when new. Gasoline must **not** be used near a fire, nor where its vapor can be carried to a fire (see § 40). **Non-inflammable** liquids should be used for household dry-cleaning.

Often our problem of cleansing is not to wash the **whole** garment or fabric, but to remove a **stain** or spot from some part of it. Then we must use special methods, first making sure that the materials used to remove the stain do not injure the cloth or its color. An excellent way to remove a **grease,** or **wax,** spot, is to wet it with benzine, and then to press it, by means of a **warm** flat-iron, between blotters. To remove a **paint** stain from a fabric we need usually remove only the **linseed oil** (see § 31) by means of benzine or gasoline. When we have removed the oil, we can generally remove the "white lead" by brushing or rubbing. In old **milk** and **cream** stains the water of the milk will have evaporated, leaving the fat in the fabric. The method to use is that for grease. **Iron rust** is a base; hence we use an acid to remove it, if the fabric will permit. Very dilute hydrochloric acid, or lemon juice and salt, will do. We must then neutralize the acid with baking soda and water, and finally rinse the cloth thoroughly. **Ink** stains are often hard to remove without injury to the fabric. **Fresh** stains are usually taken out by fresh milk. **Old** stains are soaked in water and treated with a 10% solution of **oxalic acid.** The acid is a poison, and must be rinsed out with water. The spot is then treated with baking soda and water, or with ammonia water, so that any acid that remains may be **neutralized.** Old-fashioned inks contained **iron** compounds; hence stains caused by them are treated like iron rust.

255. Summary.— **Acids** are sour substances present in fruit, vinegar, pickles, sour milk, and the like. The most important acids used in industry are **sulphuric, nitric,** and **hydrochloric** acids.

Acid solutions turn blue litmus **red,** corrode metals, neutralize bases, cause limestone and other carbonates to give off carbon dioxide, and destroy fabrics, especially cotton and linen.

Bases, or **alkalies,** have a bitter taste, turn red litmus blue, change grease into soap, destroy skin and flesh, neutralize acids, and destroy fabrics, especially wool and silk.

Neutralization is the action between the solution of an acid and that of a base. After neutralization the solution contains a **salt.**

Cotton and **linen** consist chiefly of long, hollow fibers of cellulose.

Wool consists of short, thick cells having overlapping scales.

Dyes may be absorbed by a fabric or combined with it.

The **washing of clothing** removes dirt, opens the pores of the cloth, and destroys bacteria.

Soap consists of the sodium (or potassium) salts of complex acids obtained from fats and oils.

Soap solution **cleanses** by breaking up grease and dirt into tiny particles and surrounding them, so that they are carried away by water. The **scum** formed when soap is put into "hard" water is usually a lime soap.

Dry cleaning is washing in gasoline or a similar liquid.

256. Exercises.— 1. Limewater is sometimes added to milk that is given to a child or an invalid. Tell why.

2. "Galvanized" iron is iron covered with zinc. Is it a safe material for dishes in which fruits are cooked? Why? Is a copper-plated dish safe? Is a "tinned" dish safer? Why?

3. How can you tell whether a soil is "sour," or not?

4. Spots of limestone often collect on a glass water-pitcher; can you suggest why? They are easily removed by a little vinegar or lemon juice. Why?

5. Why is it not enough to wash clothing in cold water, even with soap? Why is it not enough to use hot water, without soap?

6. Do you think it is a good practice for a laundry to use strong "sours," or acids, for the washing of clothing? What materials are especially injured?

7. Why should wool be washed with a mild soap, and in warm, but not hot, water?

8. How does hard water injure a fabric?

9. Why is "bluing" used in the laundering of white goods?

10. What is the advantage of starching laundered goods?

11. Should towels be ironed, or not?

257. Projects.— 1. Put labels upon the bottles, boxes, and cans in which household chemicals are kept: those for the laundry, the kitchen, and for medicinal and toilet use; so that there may be no danger of mistaking one for another.

2. Bring several samples of vegetables and fruits to the class and show, by two tests, that each does, or does not, contain an acid.

3. Prepare home-made potash lye from wood ashes, and show its properties to the class.

4. Test washing soda and samples of washing powders, toilet soaps and laundry soaps before the class, and determine whether each has an acid, a basic, or a neutral reaction.

5. Find some old mortar, and show the class what happens when the mortar is treated with an acid; also what is given off in the process. Draw some conclusion as to what happens when mortar "sets," or hardens.

6. Report to the class how woolen clothing should be washed so

that it will not shrink and will remain soft and porous. Ask a good laundress for the facts.

7. Prepare an essay or debate upon the topic: "The quantity of soap used by a country is a measure of its degree of civilization."

8. Obtain several pieces of woolen cloth of different colors, and stain them with dilute hydrochloric or sulphuric acid. Then show the class how to remove the stains by means of a paste of baking soda.

9. Soak a piece of cotton cloth in dilute hydrochloric acid, let it dry in a warm place, and show the cloth to the class.

10. Measure the dimensions of a new piece of white flannel cloth, and wash it in hot water containing a strong laundry soap. Dry it thoroughly and again get its dimensions. Report results to the class.

11. Prepare an emulsion of kerosene and soap solution (§ 253), and show it to the class. Prepare a second emulsion from linseed oil and four times its volume of limewater.

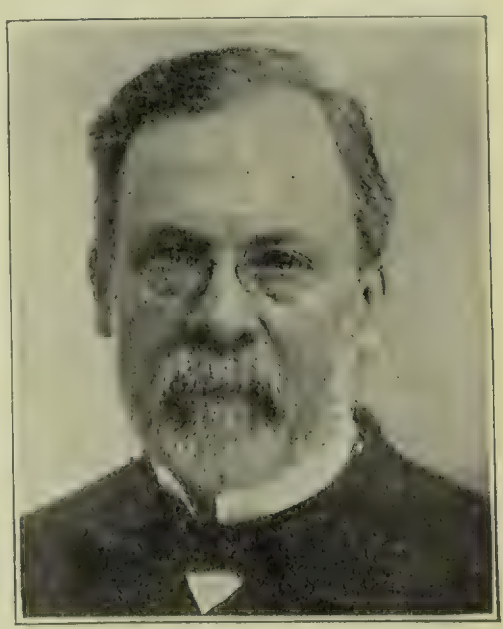
12. Prepare crystals of potassium nitrate (saltpeter) by neutralizing potassium hydroxide by means of dilute nitric acid (see § 249).

258. References.— BALDERSTON: *Laundering.* DODD: *Chemistry of the Household.* HESSLER AND SMITH: *Essentials of Chemistry.* RICHARDS AND ELLIOTT: *Chemistry of Cooking and Cleaning.*

ANTOINE LAVOISIER (1743-1794). Proved that burning is union with oxygen.

MICHAEL FARADAY (1791-1867). Discoverer of electromagnetic induction and inventor of dynamo.

S. F. B. MORSE (1791-1872). Inventor of the electric telegraph and its alphabet.



LOUIS PASTEUR (1822-1895). Founder of the science of bacteriology.

CHAPTER XV

HOW MAN DOES HIS WORK

259. Why We Use Tools.— The people of today live in better houses, wear better clothing, eat better food, and have more leisure than the people of the past, largely because of better tools and machines. Even a very simple machine enables a man to do his work to better advantage and with less physical effort, and to do more in a given time, than if he has only his own hands to help him. We see this very clearly if we watch a farmer about his work. He **pries** a stone or log instead of lifting it. In raising boards or hay to the loft of a barn he uses a **pulley** with a rope over it. By pulling downward on the rope he pulls the weight upward. He splits logs with a **wedge,** and cuts down trees by the use of axe and saw. He plows with a sloping knife, or **plowshare.** Instead of dragging heavy objects over the ground, he usually puts wheels or rollers under them, because **rolling** friction is less than **sliding** friction.

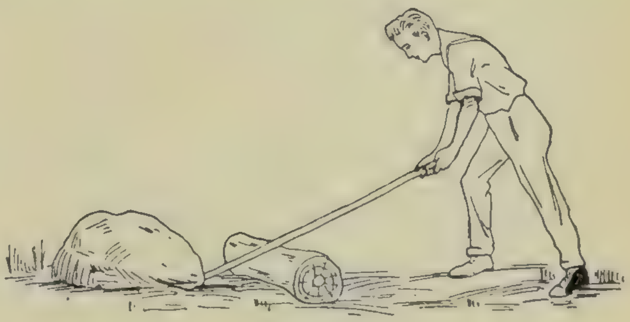


FIG. 237.
Prying a stone up with a crowbar.

260. A Crowbar as a Machine.— Watch a person prying a heavy object, as in Fig. 237, with a crowbar. He puts one end of the crowbar under the object, pushes a support (a stone or log; we call it a **fulcrum**) as far as possible under the "weight" end of the crowbar, and then uses his own force to bear down upon the free end. Thus a person weighing, say 150 pounds, can lift an object weighing 750 or 1000 pounds, or even more. Just how much he can lift depends on how near the object he can place the fulcrum.

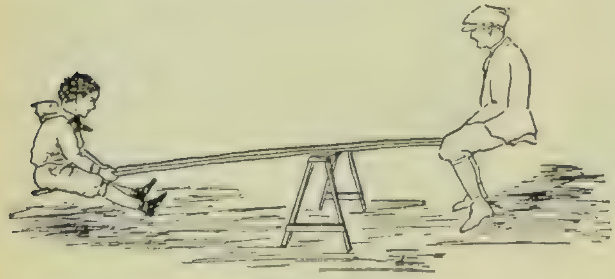


FIG. 238.
The teeter as a lever.

A study of a "teeter" will help us to understand the principle of the crowbar (Fig. 238). We know very well that a boy weighing 90 pounds can balance a man weighing 180 pounds, *if only we put the fulcrum in the proper place.* If we disregard the weight of the teeter board itself, then the boy must be twice as far from the fulcrum as the man. If the board is 15 feet long, the boy must be 10 feet from the fulcrum, and the man, 5 feet. What must be the position of the fulcrum in the case of a boy weighing only 45 pounds?

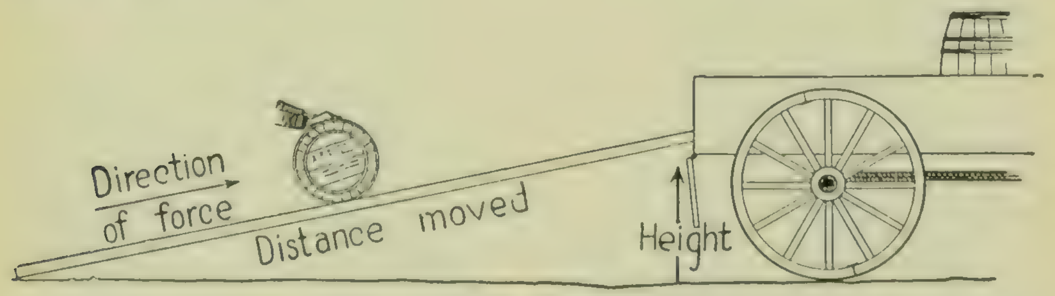


FIG. 239.
By using an inclined plane we push the barrel a greater distance than if we lifted it vertically, but we exert less force.

261. The Inclined Plane.— If you wished to raise a 200-pound barrel from the ground to a wagon, you would probably roll it up a **sloping board** (Fig. 239).

If the board were 12 feet long, and its higher end 3 feet from the ground, you would need to exert a force of only 50 pounds *parallel with the board*, to push the barrel into the wagon. You would need to roll the barrel 4 times as far as the distance you wish to raise it, but you need exert only $\frac{1}{4}$ of the force.

Hillsides are inclined planes. We prefer to go up gradual slopes rather than steep ones, because we can get a better footing, also because we need not lift the weight of our bodies so high at each step. Stairways and stepladders are inclined planes in which the height of the **risers** and the width of the **treads** have been made as comfortable as possible. We must not forget, however, that in using sloping boards, sloping ground, or stairways, we are making an **exchange**. We go a **greater distance** than if we went vertically upward.

262. The Advantage of Machines.— People sometimes imagine that in some mysterious way a machine creates energy. How is it that a boy weighing 90 pounds can lift a man weighing 180 pounds, by the use of a "teeter"? The boy must move **twice as far** as the man. In order to lift the man 1 foot, the boy goes down 2 feet. How is it that a man pushing downward, with a force of 150 pounds, on the longer arm of a crowbar, can raise a 750-pound stone on the shorter arm of the crowbar? The answer is that the force must move **5 times as far** as the stone; therefore the force need be only $\frac{1}{5}$ as great as the weight it lifts. In rolling a barrel up an inclined place you likewise prefer to move the barrel a greater distance by exerting a small force, rather than exert all the force needed to lift it vertically upward.

Tools and machines do not create any energy. They simply make it possible for us to apply force in a convenient direction or at a convenient place; or they allow us to exchange a small force exerted through a great distance for a large force exerted through a correspondingly shorter distance.

The exchange we make in using a sewing machine is the opposite of that which we make in the crowbar and the inclined plane. Sewing by hand is hard, not because it requires much strength, but because it is slow. With a sewing machine a seamstress can exchange her strength for greater speed.

From the facts we have learned we can understand the **law of machines:**

The power exerted, multiplied by the distance the power moves, is equal to the weight lifted (or resistance overcome) multiplied by the distance the weight moves.

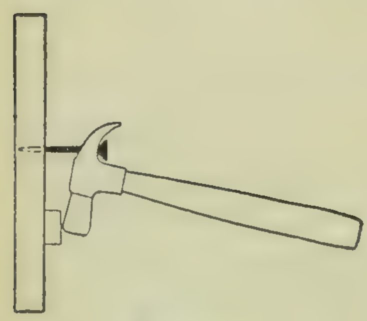


FIG. 240.
A claw hammer is a lever; where are the weight, the force, and the fulcrum?

263. The Lever.—The crowbar and the teeter are forms of the same simple machine, the *lever;* the *claw hammer* is another familiar form (Fig. 240). We can hardly draw a nail out of a board by pulling with all our might, yet by the use of a claw hammer we do the work with little effort.

A **balance** (§§ 6 and 109) is really a lever. In **fish scales** (Fig. 241) the arm holding the pan is the shorter; hence a heavy object on the pan can be balanced, or "weighed," by a small "weight" on the longer arm. The **weighted gate** (Fig. 242) and the **well sweep** are other examples of the lever.

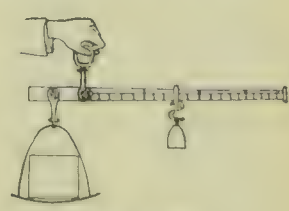


FIG. 241.
Fish scales.

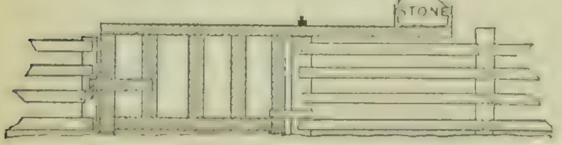


FIG. 242.
In the weighted gate the stone nearly balances the weight of the gate, so that very little effort is needed to lift the gate.

Classes of Levers.— We divide levers into **three classes,** according to the way in which the **fulcrum,** the **power,** and the **weight** (or resistance to be overcome) are placed with respect to one another. The levers already described are of the **first class:** the fulcrum is between the power and the weight (Fig. 243). We call the "arm" of the lever between the fulcrum and the weight, the **weight arm,** and that between the fulcrum and the power, the **power arm.** The **law of levers** is:

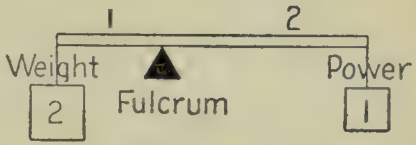


FIG. 243.
A lever of the first class. Product of weight by weight arm equals that of power by power arm.

Power × Power Arm = Weight × Weight Arm.

In the **nutcracker** (Fig. 244) the resistance (the nut) is between the fulcrum and the power. This is a lever of the **second class** (Fig. 245). The **wheelbarrow,** when used in **lifting** a weight, is also a lever of the second class. The axle of the wheel is the fulcrum, the power is applied to the handles, and the weight is between the fulcrum and the power. If you put a 100-pound piece of ice 1 foot from the axle, and grasp the handles 5 feet from the axle, you need exert a force of only 20 pounds to lift the ice. In this calculation we disregard the weight of the wheelbarrow.

FIG. 244.
A lever of the second class. To get the greatest effect, where should the nut be placed?

Levers of the **third class** have the fulcrum at one end, as in those of the second class, but the power is applied between the weight and the fulcrum. The tread of a grindstone and that of a weaving loom (Fig. 246) are third-class levers; so is the human **forearm** (Fig. 247).

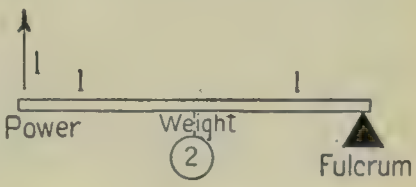
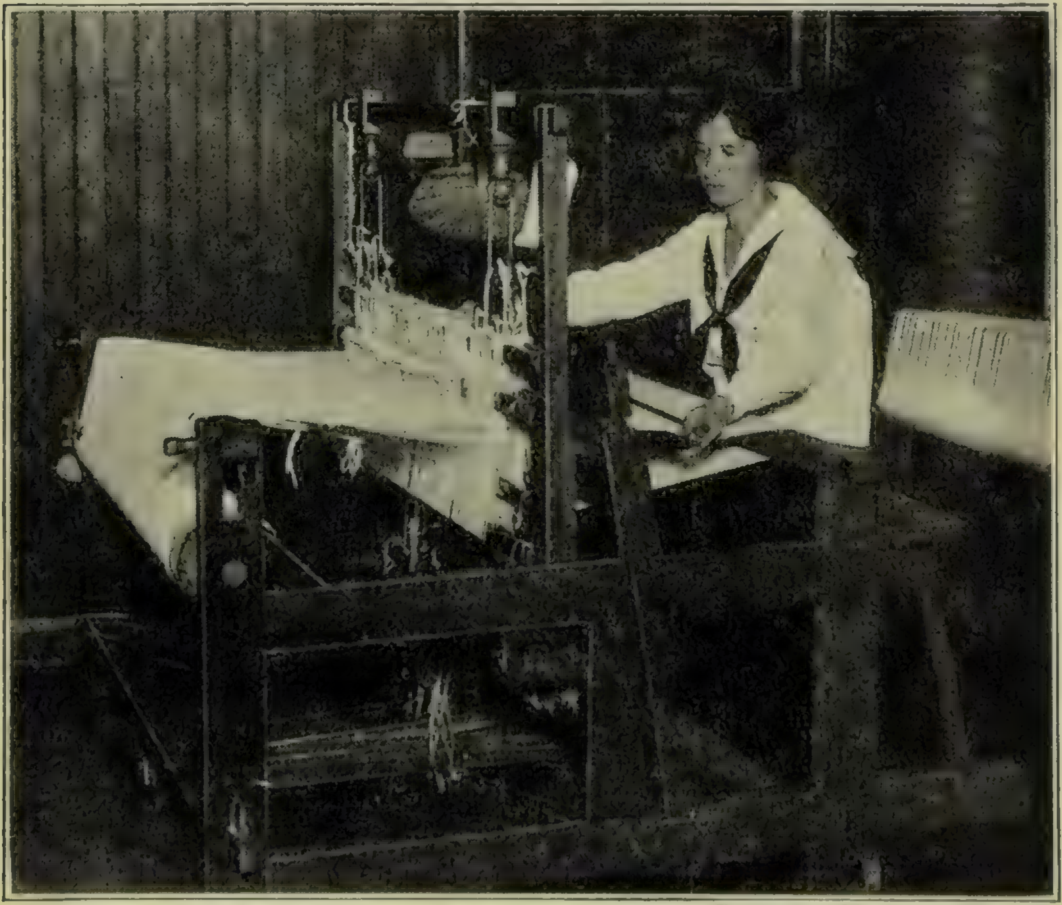


FIG. 245.
What are the lengths of weight arm and power arm in this lever? Compare the weight with the power needed to lift it.

264. Kinds of Machines; Pulleys.—If we examine the tools and machines that men use, we find that we can reduce them to **six** simple machines:

(1) **Lever.**	(4) **Inclined Plane.**
(2) **Pulley.**	(5) **Wedge.**
(3) **Wheel and Axle.**	(6) **Screw.**

If we think of the wheel and axle as a form of lever, and the wedge and screw as forms of the inclined plane, we can reduce the number to **three.**



Courtesy of Mrs. Anna Ernberg.

Fig. 246.
An Ernberg weaving loom in use in the Fireside Industries, Berea College, Kentucky.

In the simplest form of the **pulley** (Fig. 248, *a*) we cannot lift more than the power we exert; but we can *raise* a weight by pulling *downward.* Does our own weight help us in this? Such a pulley is used to lift hay into a barn loft, to hoist the sails of a ship, and to raise a flag on a flagstaff (Fig. 97, § 116).

If we have **two pulley wheels,** as in Fig. 248, *b*, two cords support the weight, while the hand pulls on only one cord; hence a power of 1 pound can balance a weight of 2 pounds. We get this advantage because the one cord must descend twice as far as the weight rises.

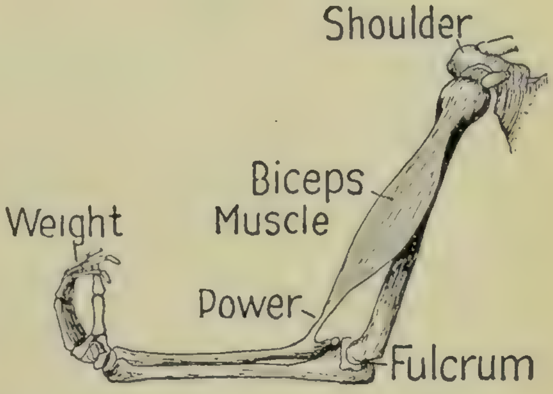


FIG. 247.
The human forearm as a third-class lever. What is the relation of the power to the fulcrum and the weight?

265. The Wheel and Axle. — The wheel and axle (Fig. 249) is a machine in which the power applied on the wheel moves a distance equal to the circumference of the wheel, while the weight attached to the axle moves only through the circumference of the axle.

In a **winch,** or windlass (Fig. 250), the power is applied to a crank. To raise the weight a height equal to the circumference of the axle, the power must be exerted through one complete turn of the crank. In a **derrick,** or crane, used by workmen in raising loads of brick or stone to the top of high buildings, there is a combination of a wheel and axle with a system of cog wheels and pulleys.

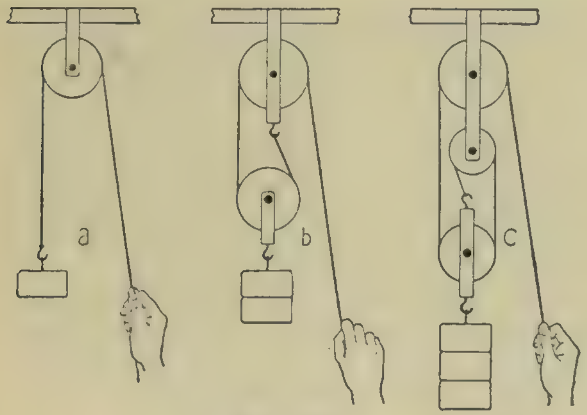


FIG. 248.
In *a* the pulley is simple; a pull of 1 lb. just supports a 1-lb. weight. In *b* and *c* the pulleys are compound; a 1-lb. pull will support 2 and 3 lbs., respectively.

266. The Wedge.— A wedge (Fig. 251) is really two inclined planes with their bases joined. It is made of hardwood or iron and is used to split logs and rocks, and sometimes to raise a heavy weight a short distance. If the length of a wedge is 6 times its thickness, we must drive it into a log 6 inches in order to force the wood apart 1 inch. Show that the **axe,** the **pin,** and the **needle** are wedges.

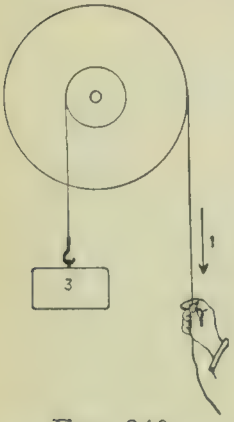


FIG. 249.
The wheel in the figure has a circumference (also a diameter) 3 times that of the axle; hence 1 lb. on the wheel supports 3 lbs. on the axle.

267. The Screw.— The screw (Fig. 252) is really a long inclined plane arranged in a spiral. The slope of the ascent corresponds to the **pitch** of the screw. If a screw has 6 **threads** to the inch, we must go 6 times around the screw to rise 1 inch. A small force can thus produce a large effect; for the power must go through a long distance in order to make the screw itself advance a very short distance.

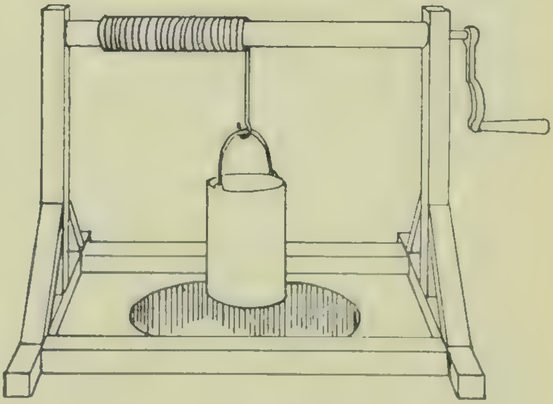


FIG. 250.
A winch used for raising water from a well.

FIG. 251.
Splitting a log by means of a wedge and maul.

Suppose that the jackscrew of Fig. 252 has 6 threads to the inch, and that the circle through which we can turn its handle is 100 inches in circumference.

The power on the handle must move 100 inches to raise the weight $\frac{1}{6}$ of an inch. But, on the other hand, a force of 1 pound on the handle produces a force of 600 pounds on the weight. Screws are used not only to force pieces of wood or metal together, and for lifting weights, but also to produce great **pressure**, as in the letter-copying press, the vise, and the screw-press nutcracker.

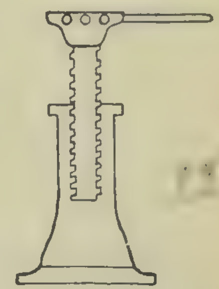


FIG. 252.

The jackscrew enables us to raise great weights, such as wagons or houses, short distances by the use of a small force.

268. Exercises.—1. What kind of simple machine is a can-opener, a pair of shears, an oar, a nail, a screw-driver, a knife, a fork, the cover of a Mason jar?

2. To what class of levers do the following belong: a wheelbarrow, sugar tongs, the handle of a hoe, a pump handle (Fig. 14), a claw hammer?

3. What simple machine can you find in a door knob, an egg beater, a weighted window, a door, a key turned in a lock, an automobile-engine crank, a pin-wheel, a coffee-grinder, a carpenter's brace and bit? A wrench?

4. What are the different simple machines used as nutcrackers?

5. What kind of machine is a bread-mixer? A saw? An axe? A fish-line reel? The treadle of a sewing machine?

6. Where should you put the load in a wheelbarrow to make the force needed for lifting as small as possible?

269. Friction.— Why do we oil a machine? Because not even the smoothest surface we can produce is free from all roughness, and two surfaces which rub together wear each other down. A thin coating of oil or grease used as a **lubricant** allows the two surfaces to pass each other without so much sticking and rubbing; hence we get more *useful work* out of the machine.

Because of **friction** the law of machines is not exactly true when we actually use a machine. But while friction represents lost effort (§§ 50 and 112), *some* friction is usually necessary in order that a machine may "work." Thus, a barrel must "stick" slightly to an inclined plane, or we cannot roll it up; a rope passed over a pulley must adhere to the rim of the pulley, or the pulley wheel will not turn when the rope is drawn in. We know how difficult it is to walk upon a highly polished floor, owing to the lack of friction between our shoes and the floor. Also, heavy objects that are to be moved horizontally are placed on rollers or wheels, if possible, because **rolling** friction is much less than **sliding** friction. The wheelbarrow illustrates this admirably, also the use of casters on heavy furniture.

270. How a Kite Uses Wind.— We are now to study four machines: the **kite,** the **windmill,** and the **sailboat,** which "work" because of force exerted by air in motion, and the **airplane,** in which the machine itself moves through the air, but the effect is the same as though the machine were still, and the air were pushing against it. We have already studied the way in which air exerts force by flowing down into the space occupied by a lighter body and forcing the body upward (§ 120). This **buoyant force** of air raises balloons and dirigibles (Fig. 253).

Courtesy of U. S. Navy Department.

FIG. 253.

The U. S. S. Shenandoah, built and operated by the U. S. Navy as a long-distance scout. It is 680 feet long, and contains 20 balloons filled with helium (see § 152).

A **kite** (Fig. 254) is a device by which we can use part of the force of a **horizontal** wind to push a body **upward.** If we adjust the kite-string on the "bridle" of the kite in such a way that the wind strikes the plane of the kite **perpendicularly,** the wind cannot raise the kite. If we hold the kite horizontal, that is, **parallel** with the wind, the wind slides past, and the kite can use none of its force. But if we adjust the string on the bridle so that the kite is held **inclined** to the wind, the force of the wind is divided in its effect. One part of it acts perpendicularly to the plane of the kite, and is resisted by the string; but another part of it acts vertically upward, and raises the kite into the air.

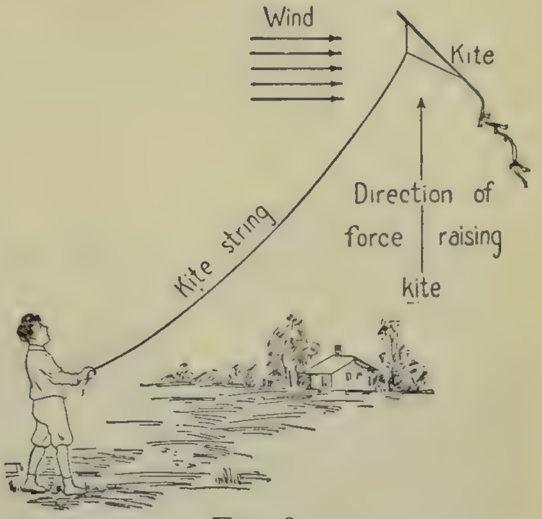


Fig. 2

Part of the force of the horizontal wind pushes the oblique kite-plane upward.

271. The Airplane.— We must think of an airplane as a great kite (Fig. 255). The essential things about it are one or more **planes,** much wider than they are long, and a powerful **motor** or engine, to force it rapidly **edgewise** through the air. The airplane rises as a kite rises in a wind, or as the bow of a ship rises when it is driven rapidly through water.

The **explanation** of the action of the air upon the airplane is practically the same as if the airplane were still, and the air were in rapid motion. When the motor forces the plane forward, the force (resistance) of the air is divided in its effect, as in the case of the kite. One part opposes the forward movement of the plane, and must be overcome by the motor. Another part of the air's force acts vertically upward, and raises the plane, against gravity, into the air.

The best **material** for the wings of an airplane is probably linen cloth stretched over a frame of walnut wood. Other woods are used, and in some planes aluminum has been found suitable. Both linen and wood must be waterproofed. The **wings** are **curved** downward slightly at the front; so that a cross section of an airplane's wing looks like that of a bird's wing. With such a shape the wings have great lifting power.

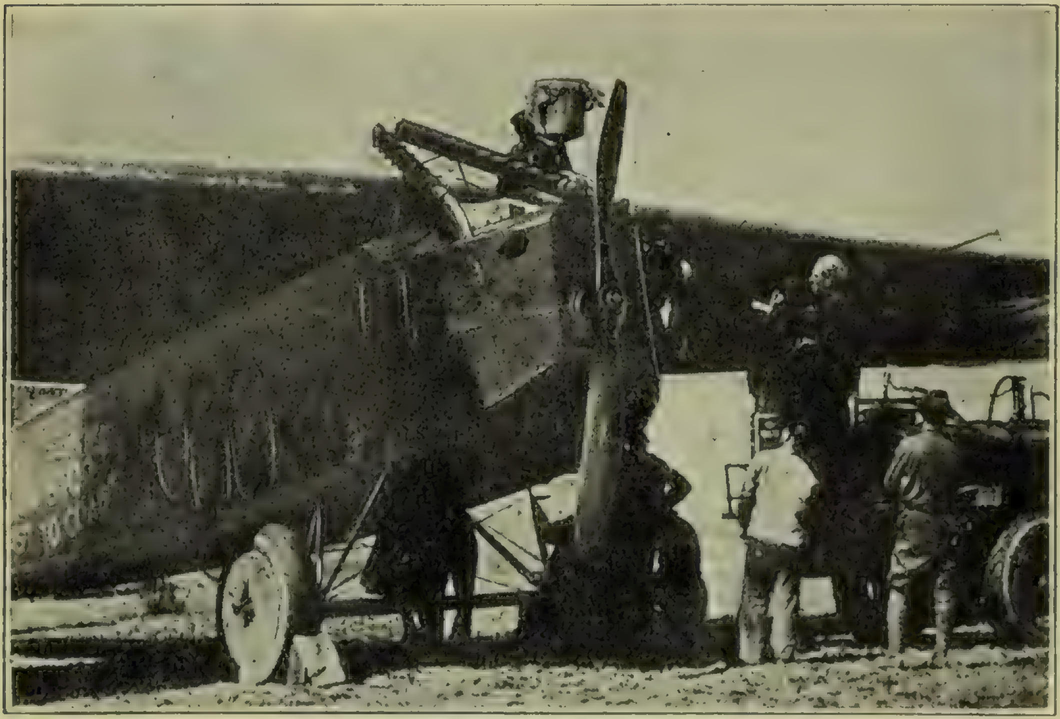


FIG. 255.
Monoplane just before its start on a non-stop flight from Long Island to San Diego.

Propellers driven by the engine force the airplane forward. They usually have two blades and a diameter of from 6 to 10 feet. They may be either in front of the engine or behind it.

Steering a straight course through air is no easy matter, and sailing in the air is as rough as sailing over the sea. Wherever the air becomes less dense, the airplane falls into a "hole"; wherever the air's density becomes greater, the airplane strikes a "bump," and rises over the obstruction as a ship rises over a high wave. So the airplane tips forward or backward ("pitches"), or from one side to the other ("rolls") as a ship does. Tipping forward or backward is avoided by the use of **horizontal rudders** on the stern of the airplane. To avoid tipping to one side some airplanes have **flaps** attached to the main plane. In other planes the aviator avoids sidewise tipping by **warping**, or drawing down, the rear tips of the lifting planes. Thus, if the airplane is tipping too far to the right, the aviator warps the tip of the left plane; the left side then **drags** against the air more than the right, and prevents tipping to the right. The pilot's own weight helps him greatly in giving his plane stability; when the plane tips to the right, he leans instinctively to the left. We do the same when rounding a curve in an automobile. The pilot turns his airplane to the right or left by means of **vertical** rudders attached to the stern.

An airplane has **wheels** as well as wings and propellers. The propellers force the machine along the ground at greater and greater speed until the air has the necessary lifting power. The wheels are needed for safe alighting as well as for starting. In a **hydroplane** small boats are attached to the bottom of the machine, so that it can start from, and alight upon, water.

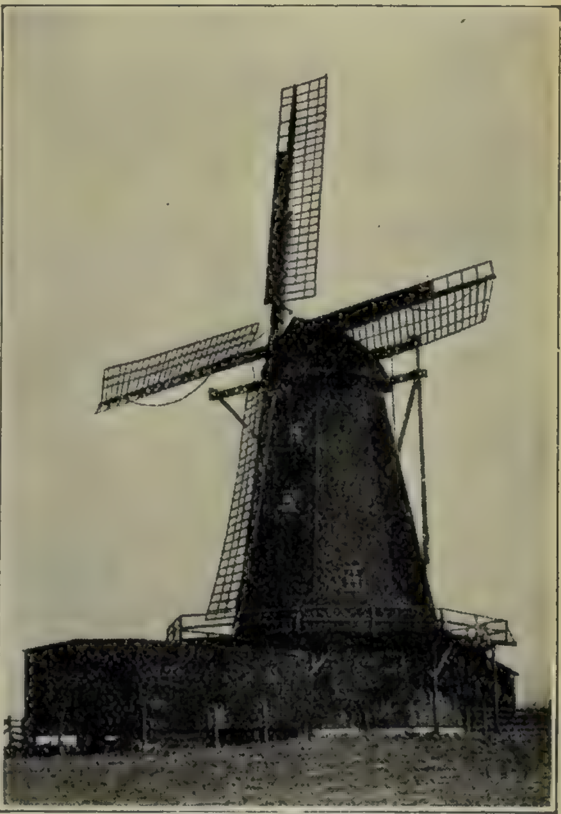

Copyright Underwood & Underwood.

FIG. 256.
A windmill of Dutch type, near Chicago, built in 1867.

Success with airplanes had to wait until the right kind of a gasoline motor was constructed (§ 275). Modern types of airplane motors develop 150 to 180 horse power (§ 116) from an engine weighing only about 300 to 500 pounds. When we remember that, in order to remain in the air, an airplane must carry not only the aviator, but also a considerable supply of gasoline and lubricating oil, we realize that the weight of the engine in proportion to its horse power is a matter of great importance. Ordinary airplanes must have their **filling stations,** just as automobiles must.

272. Windmills.— Windmills (Fig. 256) may seem to be very different machines from kites and airplanes, but they, too, move because of force exerted by air **obliquely** against a plane. A windmill consists of several planes, or **sails,** fastened to a **hub.** A **vane** attached to the hub forces the sails to face the wind. As the wind strikes each plane **obliquely,** it produces forward motion, and the forward motion of all the planes causes the hub, or wheel, to revolve. The "pin-wheel" used by children is a miniature windmill. For the pumping of water, the revolving wheel is attached to the piston of a pump (§ 14).

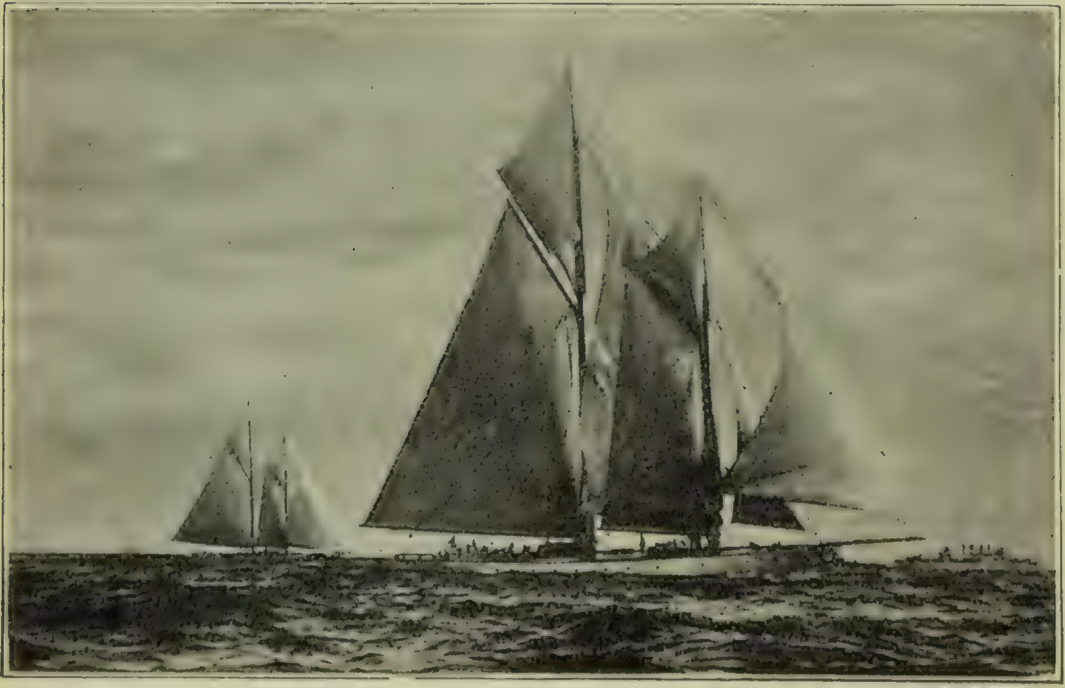


FIG. 257.
The two-masted schooner *Vagrant* at the close of a race.

273. The Sailboat.— Early man made few discoveries that helped him more in his progress than the use of sailboats; for these enabled him to travel long distances by water.

The sailboat is a machine (Fig. 257). We can readily understand why a boat sails "before the wind." The sail merely provides a large area for air pressure. However, a sailboat permits us to sail not only in the direction of the wind, but **obliquely** to the wind. We can thus **exchange** rapid motion "with" the wind for slower motion in other directions (Fig. 258). No sailboat can go directly against the wind.

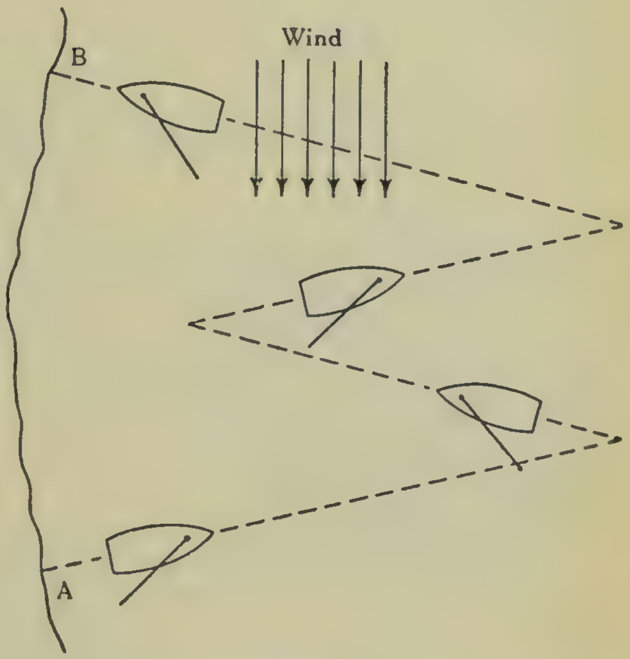


FIG. 258.
The boat can go from A to B, against the wind, by "tacking" back and forth obliquely to the wind.

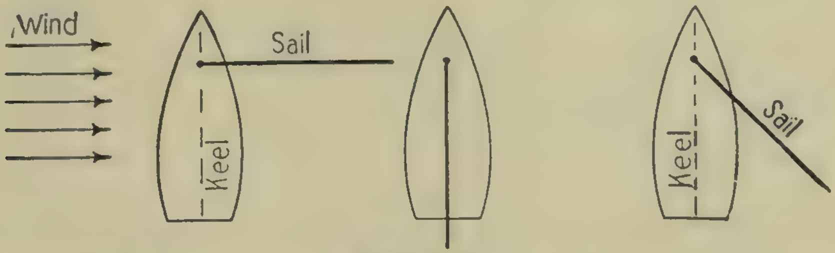


FIG. 259.
Three positions of the sail with respect to the wind and the keel.

A sailboat must have a **keel,** or **centerboard,** or it will "drift" with the wind. A keel is a projecting strip on the bottom of a boat. A centerboard is a movable keel, to be drawn up within the boat when the boat is in shallow water. If we try to push a vertical board

sidewise under water, the water resists being pushed out of the way. In the same way the resistance of the water against the keel keeps a sailboat from sidewise drifting.

If the sail is let out completely (Fig. 259), no part of the wind presses against it. If the sail is hauled in completely, there is only a slow, sidewise motion, which the keel resists. In this condition the boat is easily capsized. But if the sail is set **obliquely** to the keel, only a part of the wind's force is used in pushing the boat sidewise, while another part pushes it forward.

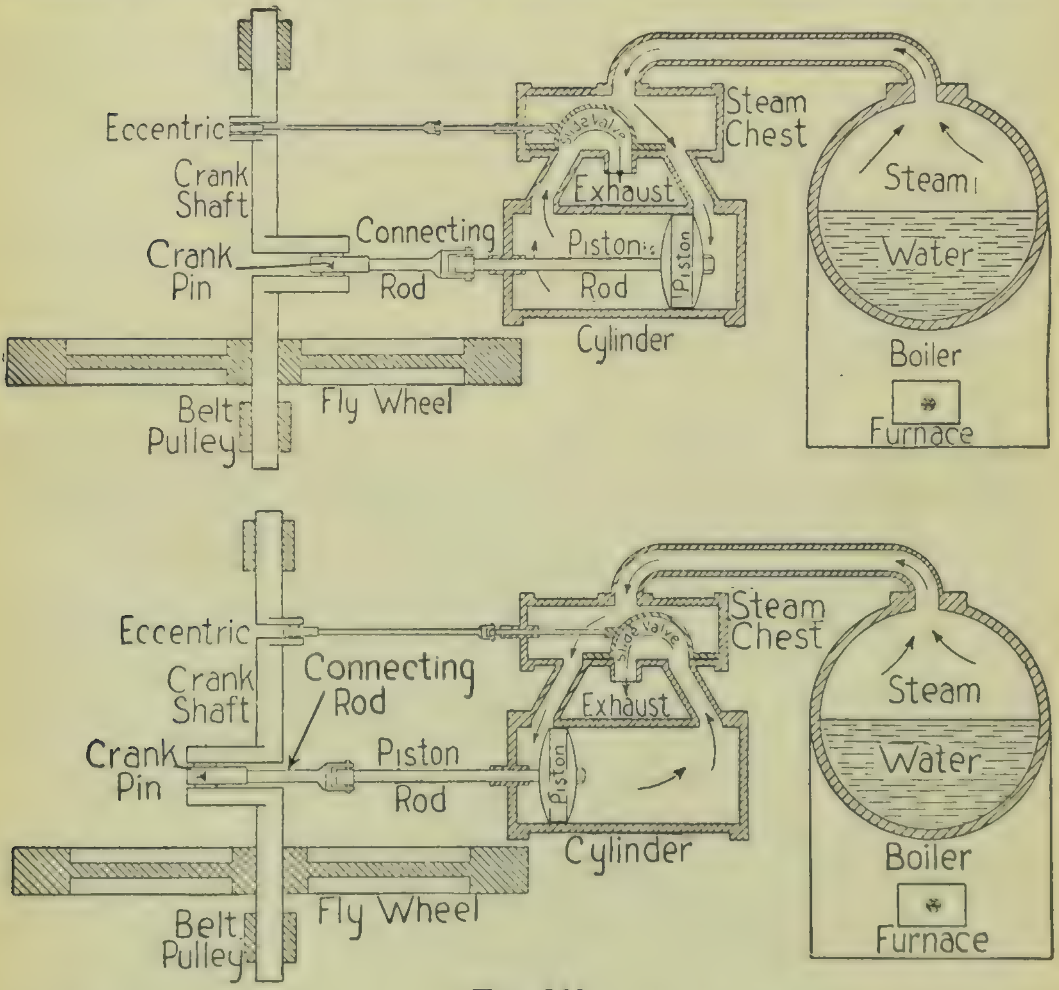


FIG. 260.

Positions of the parts of a steam engine at the beginning and end of a stroke. Trace the course of the steam from the boiler to the cylinder for both positions of the piston. Note the changes in position of the slide-valve, piston-rod, connecting-rod, crank, and eccentric.

274. The Steam Engine. — As we already know (§§ 89 and 112), steam engines run because of force exerted by **expanding steam.** The steam is produced in a **boiler** (Fig. 260), and is not allowed to escape until it has a high pressure. Then some of it is allowed to expand, first on one side, and then on the other, of the **piston,** to which it gives a to-and-fro motion. This two-way motion of the piston is changed to circular motion by means of a **shaft,** to which the piston is joined by a **connecting-rod.**

Steam is admitted, first on one side of the piston, and then on the other, by the action of the **slide-valve.** The **eccentric,** which turns with the shaft, controls the slide-valve's motion, and thus regulates the entrance of steam from the **steam-chest** to the **cylinder,** in which the piston moves. Each portion of steam that has been used is driven out of the cylinder, through the **exhaust,** at the next stroke of the piston.

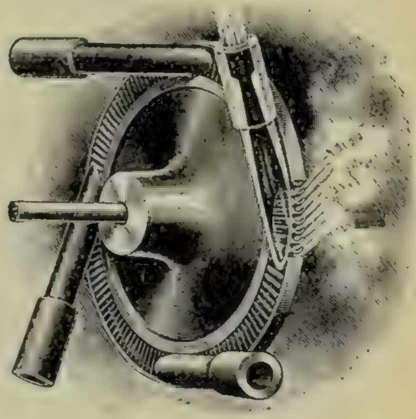
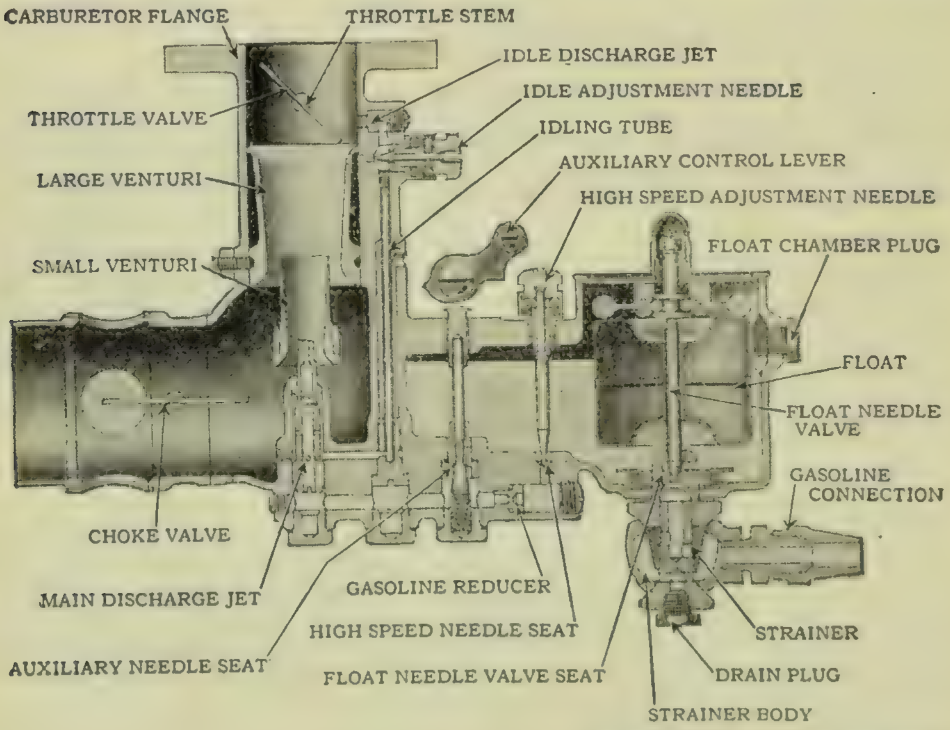


FIG. 261.

A steam turbine, in which jets of steam strike a series of blades attached to a shaft. The blades and shaft are set into rapid revolution, and the engine runs with remarkable smoothness and power.

What is the use of the **flywheel?** This is a large, heavy wheel that turns with the shaft. Twice in each revolution of the shaft, at the end of each piston stroke, there is a "dead-point," at which the engine has a tendency to stop. But the heavy flywheel stores up so much energy that its inertia (§ 111) carries it past the dead-points, and allows the motion to continue. The machinery that is moved by the engine is attached, either directly, or by means of **belts,** to the shaft. See Figs. 65, 76, and 175, also Fig. 261.

275. The Automobile and Its Engine.— The development of automobiles, like that of airplanes, had to wait until gasoline engines were perfected; why? In the gasoline engine, as in the steam engine, the power comes from the expansion of a hot gas at high pressure; but in the gasoline engine the gas is produced **inside the engine itself,** by the explosion of a mixture of gasoline vapor and air. As a result, nothing corresponding to the heavy furnace and boiler of the steam engine is needed. The gasoline used as fuel is also of low density and easily carried.



Courtesy of Stromberg Motor Devices Co.

FIG. 262.

A modern carburetor. The mixture of gasoline and air goes through the throttle valve into the cylinder of the engine.

Study the list of **essential parts** of a gasoline engine, and tell what ones are present also in the steam engine:—

(1) A **carburetor,** or mixing valve, in which gasoline and air are mixed for explosion (Fig. 262).

(2) A **cylinder** (Fig. 263) in which the explosion takes place.

(3) A **piston**, which moves in the cylinder.

(4) A **connecting-rod** and **crank-shaft** attached to the piston, for changing to-and-fro motion to circular motion.

(5) A **flywheel,** to carry the engine past the "dead points."

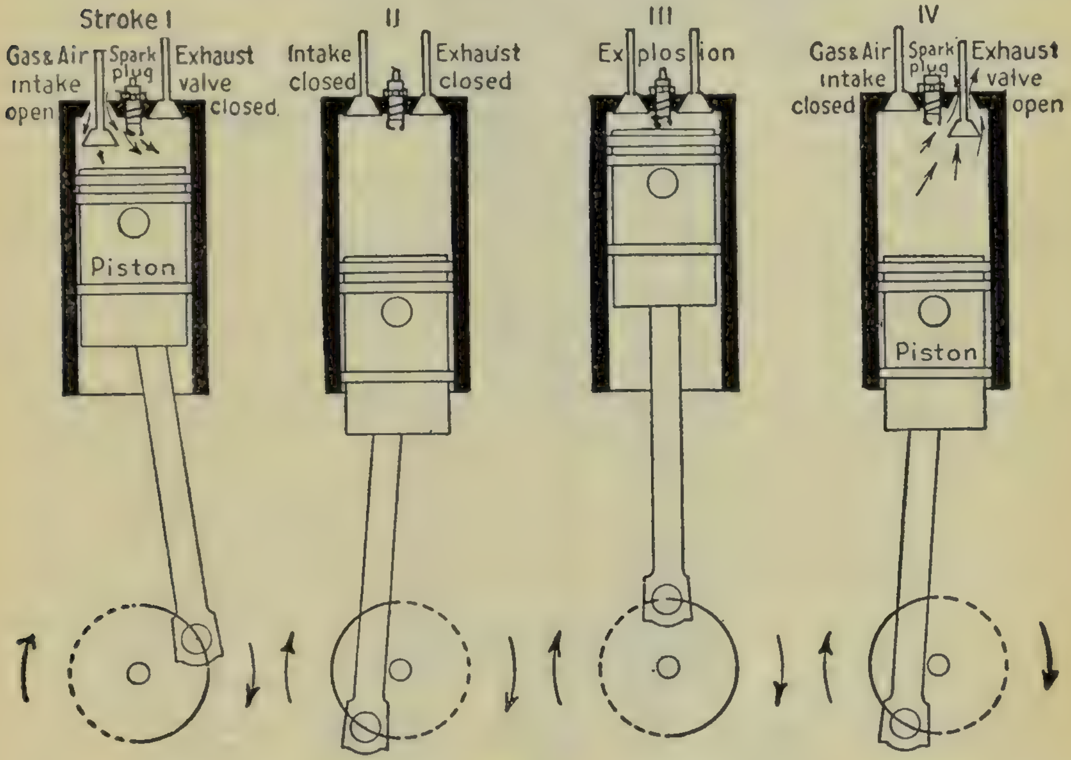
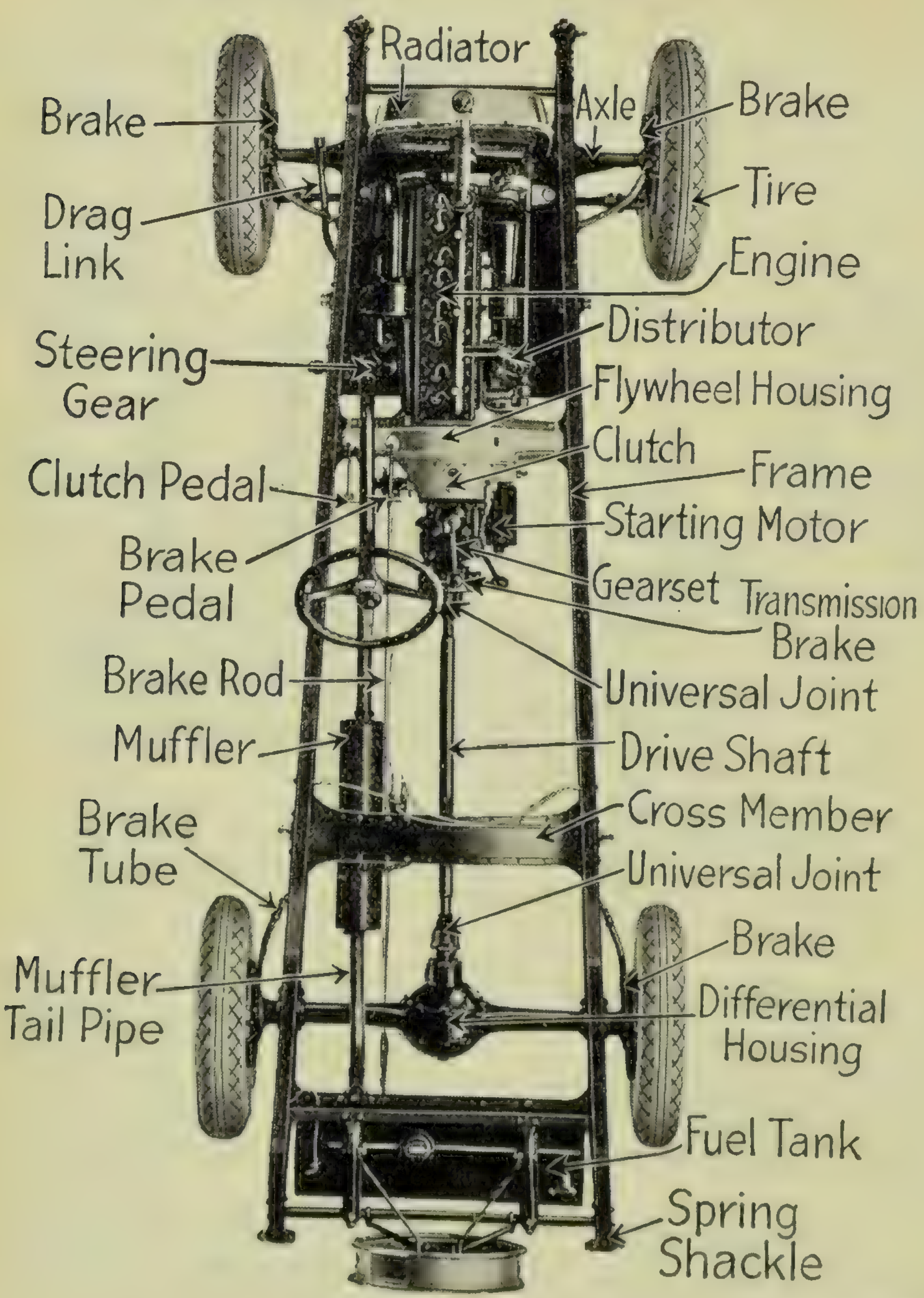


FIG. 263.

The four strokes of the ordinary gasoline engine. In stroke I the piston is beginning to descend, and the explosive mixture from the carburetor is entering the cylinder. In II the piston is just past the bottom of its stroke, and the cylinder is full of the explosive mixture. In III the piston has compressed the gas mixture, and the spark plug ignites it. In IV the piston has been hurled downward by the force of the explosion, and is just ready to rise again, pushing the waste gases out through the exhaust. Its next stroke downward is a duplicate of I.

The **spark plug,** which produces the spark that sets fire to the mixture of gasoline and air, is part of the **ignition system.** This system includes also (1) the **generator** or **battery**; (2) the **timer,** which causes the explosion to take place at just the right instant, and (3) the **induction coil,** or transformer (§ 234), which "steps up" the voltage of the battery current, so that the plug gives a "fat" spark.



Courtesy of Motor Age.

FIG. 264.
Plan view of the chassis of a modern, eight-cylinder car.

So much heat is produced in the uniting of the gasoline with oxygen (§ 29) that a **cooling system** is needed to keep the engine and its lubricating oil from becoming too hot. In most automobiles the cooling agent is **water,** which flows about the cylinders, taking up their waste heat, and then giving it off in the **radiator.** Gasoline engines need to be **lubricated** carefully, with good oil, or they will soon wear out at the bearings and the surfaces where there is **friction.**

Fig. 264 shows the **chassis** of a modern automobile. The engine is in front and the driving wheels are in the rear. The power of the engine is transmitted, through the **clutch,** to the **gears,** and then through two **universal joints** and the **drive shaft,** to the **differential** and the **shafts** of the rear axles. The **clutch** enables us to disconnect the engine from the gears. The **gears** are toothed wheels of several sizes. Through them the shaft that is turned by the engine is connected with, or disconnected from, the drive shaft that turns the rear wheels. By using different combinations of gear wheels we get "low," "intermediate," or "high" speeds, or reverse the motion of the drive wheels. The **differential** is the joint between the two halves of the rear axle; it has gears which allow the outside wheel to turn more rapidly than the inside one, when the car turns a corner. Why? What turns the front wheels?

276. Summary.— We use **tools** to do our work to better advantage.

The **law of machines** is that the **power** × the **distance** the power moves equals the **weight** × the **distance** the weight moves.

The **six simple machines** are the lever, pulley, wheel and axle, inclined plane, wedge, and screw.

A **kite** gets upward motion out of a horizontal wind.

An **airplane** rises by the force of the resisting air.

A **windmill** converts a horizontal wind into circular motion.

In a **sailboat** we exchange rapid motion before the wind for slower motion in other directions.

The **steam engine** uses the force of expanding steam.

A **gas engine** uses an exploding mixture of "gas" and air.

10 **277. Exercises.**— 1. Why is it easier to skate upon smooth ice than to walk upon it?

2. Why does an old-fashioned kite need a tail?

3. How is a rifle like a steam engine? What forms the piston? The steam chest? The cylinder?

4. Why must airplanes travel at such great speed?

5. What other fuels besides gasoline are used in "gas" engines? Is there any limit to our supply of gasoline?

6. What essential difference is there between the screw propellers and the paddle wheels of steamboats?

7. What is the advantage of windmills on a farm?

8. What are the uses of gasoline engines on a farm?

278. Projects.— 1. Show the class that a book cover is a lever.

2. Show the class how a claw hammer pulls a nail, and the mechanical advantage you get thereby.

3. Find can-openers that are levers of the first and second class, respectively, and demonstrate their action.

4. Show the class some editor's shears, tinner's shears, and scissors, and explain their differences.

5. Demonstrate the difference in construction and action of a carpenter's "rip" saw and his "cross-cut" saw.

6. Demonstrate the working of a vise, a screw clamp, or a screw-press nutcracker, and calculate the advantage you gain by using it.

7. Force a screw-eye into a board, and show the advantage of using a nail in the "eye."

8. Show how you hold your knife and fork when cutting meat, and explain what kinds of machines these tools are.

9. Arrange a system of pulleys by which you can lift 20 lbs. by pulling with a force of 10 lbs.

10. Demonstrate how a roller window shade works, and show what kind of simple machine it is.

11. Demonstrate the parts and working of a modern sewing machine.

12. Arrange the apparatus, and show the working of an inclined plane.

13. Show the construction and working of a simple kite and a box kite.

14. Bring to class a model airplane and show how it works.

15. Prepare a paper on the history of the airplane.

16. Prepare a paper on balloons and airships.

17. Bring to class a toy yacht, and show the working of the keel, rudder, mainsail, and jib.

18. Demonstrate to the class the construction and working of a gasoline engine.

19. Demonstrate the working of: (a) an automobile's **differential**; (b) the **gear shifts**; (c) the **starter**, and (d) the **brakes.**

20. Prepare a paper on the history of the automobile.

279. References.—AERO CLUB: *Navigating the Air.* BAKER: *Boy's Book of Inventions.* BURNS: *Stories of Great Inventions.* DOUBLEDAY: *Stories of Inventors.* HARPER'S: *Machinery Book for Boys.* HOLLAND: *Historic Inventions.* MAULE: *Boy's Book of New Inventions.* MILLIKAN AND GALE: *Physics.* TOWER, SMITH, TURTON, AND COPE: *Physics.* WILLIAMS: *How It Works.*

CHAPTER XVI

ROCKS AND SOIL

280. The Rocks of the Earth's Crust.— If we examine the earth's crust as it appears in an excavation or quarry, we usually find two layers: **mantle rock** and **bed-rock.**

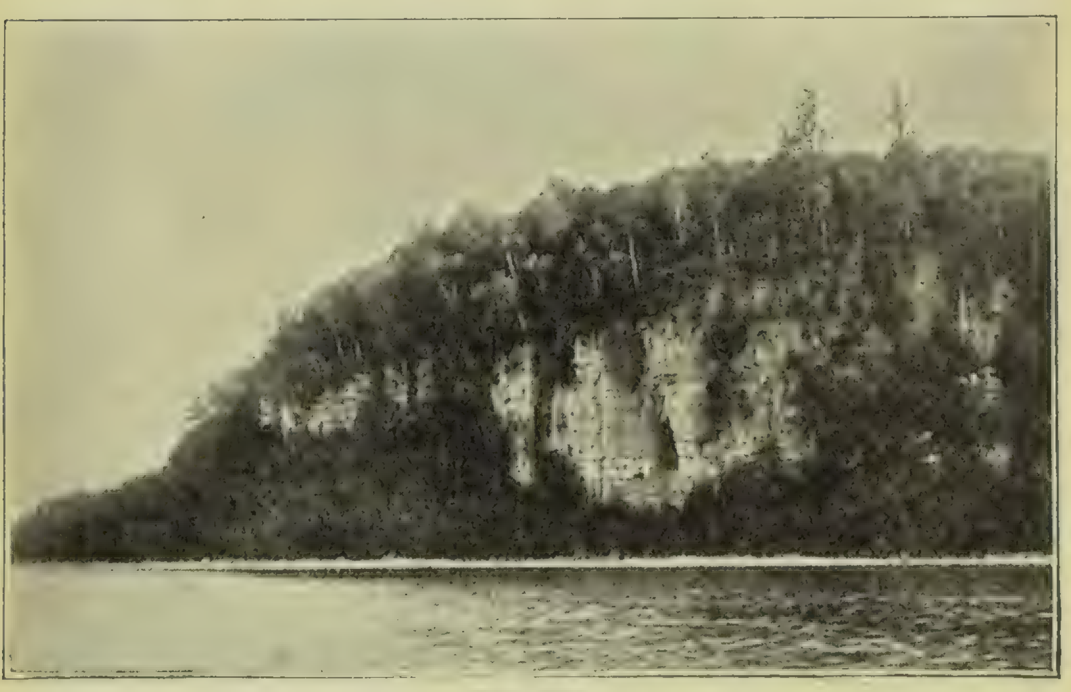


FIG. 265.
Eagle Bluff, a limestone cliff in Peninsula Park, Wisconsin.

The mantle rock is the loose, outer covering which we can work with the spade and the pick. We use part of the mantle rock for the growing of crops, and call it the **soil.** Between the soil and the bed-rock is the **subsoil.** The subsoil contains little, or no, **organic**

matter, and is therefore lighter in color than the soil. At a moderate depth the mantle usually stops, and we reach bed-rock. When bed-rock is exposed at the surface, we have an **outcrop.**

Bed-rock usually consists of minerals crystallized in compact masses, or of fragments of minerals cemented together. The most common rocks are **sandstone** and **limestone.** Sandstone consists of cemented fragments of sand. Limestone (Fig. 265) is usually made up of masses, often very tiny, of the broken shells and other hard parts of water animals (Fig. 266). These are cemented together by **calcium carbonate** (§ 62). **Conglomerate** is a gravel of various materials cemented together. When rocks lose their cementing material, they fall to fragments. Sandstones can often be crumbled in the hand, owing to the absence of such materials. What is the cementing substance in hard mortar? How may it be removed? See § 247.

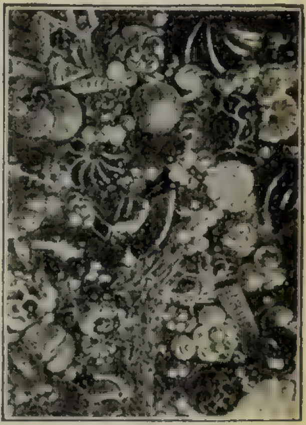


FIG. 266.

Chalk, a form of calcium carbonate, as magnified by the microscope. It is made up of the fossils of many tiny creatures. This is not ordinary blackboard crayon.

Shale is a soft rock consisting of flattened particles of clay; it splits easily into leaves.

Granite consists of several crystalline minerals: **quartz, feldspar, mica,** and **hornblende.** The quartz forms small, shiny crystals (§ 97). The feldspar is usually pink, white, or gray. The mica can be split off in very thin leaves (§ 175). The hornblende is usually dark green or black.

281. Classes of Rocks.—We can divide rocks into **two** great classes. One consists of rocks having a **layer** structure. A cross section, especially when polished, shows many parallel lines. A layer, or **stratum,** of one material usually covers a layer of another, as in the rocks under Niagara Falls (Fig. 267), in which a hard limestone rests upon a soft shale. Such rocks are called **stratified** rocks. They were deposited, as sediment, under water, hence they are also called aqueous, or **sedimentary** rocks. Limestone, sandstone, shale, and conglomerate are stratified rocks. The **most valuable** stratified rock is **soft coal** (§ 59). Stratified rocks often contain animal and plant remains, or **fossils** (Fig. 266).

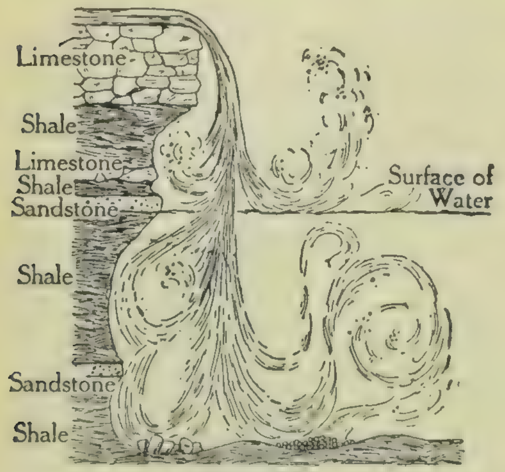


FIG. 267.
A cross section of the stratified rocks through which the Niagara River is cutting its way. Note how the layers of hard rock are being undermined by the wearing away of the soft rock. (After Gilbert.)

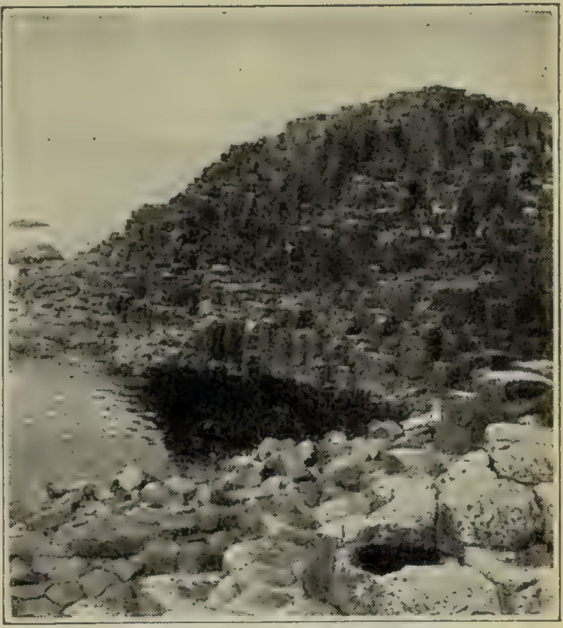
Granite does not have a layer structure; it belongs to the class of **unstratified** rocks. The minerals of granite are crystallized and closely interlaced. This is what we should expect, if the minerals had been melted together, and then had cooled very slowly.

Basalt, lava, and **pumice** are also unstratified rocks. Basalt (Fig. 268) is often called "trap rock." Lava and pumice have a structure like glass, and show no crystals. Unstratified rocks are often called **igneous** rocks; why?

Marble is an example of a **third class** of rocks. It is calcium carbonate, like limestone; but instead of showing a layer structure, it is crystalline, like igneous rocks. Marble was probably originally stratified, but has been **altered** by heat and pressure. Such rocks are called **metamorphic** rocks. **Anthracite** coal is metamorphic coal; **slate** is metamorphic shale. Often all the stages in the change from stratified to apparently igneous rocks can be seen.

282. Origin of Rocks.— How do we know that stratified rocks were formed as sediment under water, while igneous rocks were formed by the cooling of melted materials? The best way to find out how changes took place in the past is to study changes taking place today.

Imagine a small stream emptying into a quiet pond. After a rain the swollen stream brings down mud, sand, and often fine gravel. When it enters the pond, its velocity is checked, and it drops its sediment, the largest particles first, and the smallest ones last. The finest particles take a long time to settle, and are spread out over the bottom of the pond. Then another rain comes, and a second deposit is placed over the first. The largest particles of the second deposit will be on top of the finest particles of the first. In this way the sediment takes on a layer structure, and a vertical cross section of it shows the fine, parallel lines that are present in stratified rock. If now the sediment were to become very thick, producing great pressure on the lowest layers, and if a cementing material were present, the clay deposited in the pond might be changed to shale, and the sand to sandstone.



Copyright the International Stereograph Co.

FIG. 268.
The basalt columns of Giant's Causeway, Ireland.

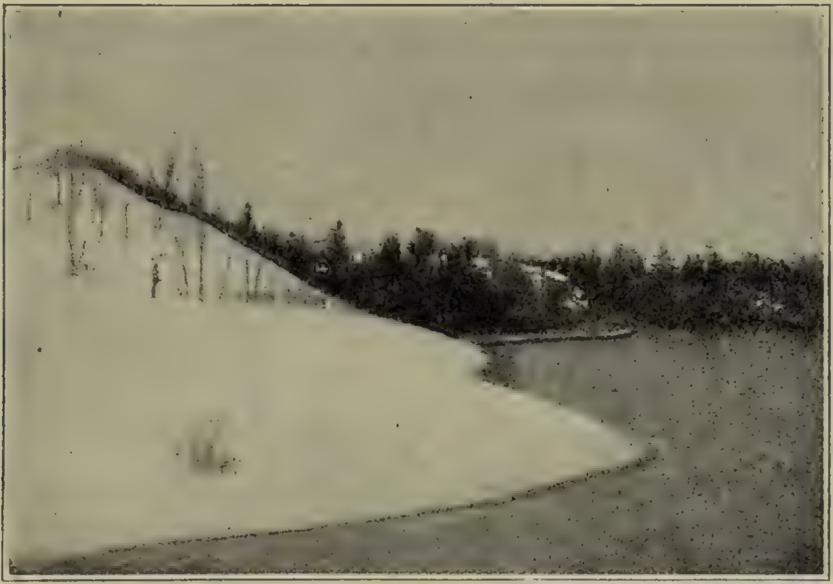
We cannot observe the formation of igneous rocks as easily as that of stratified rocks, but there are, even now, volcanic regions in which melted rock is being forced through openings in the earth's crust. Sometimes the rock hardens in a glassy, brittle form, as in **lava**; sometimes it is full of gas bubbles, and forms **pumice.** New England has no volcanic conditions today, but it must have had them in the past; for in many places there are great **dikes** of igneous rock. These represent rock cracks that were filled, from below, with lava. In Oregon large lava areas are found on the surface. **Granite** probably hardened entirely **under** the earth's surface, by very slow cooling. When we find granite as an outcrop, the rock that once covered it must have been worn away.

There are **artificial** rocks as well as natural ones. **Earthenware** articles, such as bricks, jars, and tiles, are made of clay, hardened by "firing" in a furnace. The people of ancient Babylonia and Assyria made their ordinary records, such as accounts and notes, as well as the records of their history and literature, upon **clay tablets,** and then baked the clay in the sun. **Porcelain,** china, and stoneware are made by the "firing" of a mixture of a white clay (kaolin) with quartz and feldspar. **Concrete** is made out of cement, gravel, and water. The cement and water unite and cause the mixture to "set." Cement is formed by the heating of a mixture of limestone and clay. The science of making articles out of artificial stone is **ceramics.**

283. How Soil is Made.— Have you ever seen a large rock on which plants were beginning to get a foothold? The plants were probably growing in cracks or pockets in which a little soil had accumulated. The soil was no doubt formed by the breaking off of tiny particles of the rock, and was washed into the cracks by the rain or blown into them by the wind. Each generation of plants left behind it some decaying vegetable material, which enriched the soil and formed a network that held the soil to the rock, and acted like a sponge in retaining moisture during dry weather.

Decay or **weathering,** somewhat like that just described, has taken place with all rocks exposed to the action of the "weather." At the base of every cliff there is a heap of loose material broken off from the rock above. Around every boulder, if the ground has not been disturbed, you can find chips and dust from the boulder Polished marble monuments become worn and rough, and limestone walls soon have a surface that you can rub off. We see **artificial** weathering in the wearing off of stone and concrete sidewalks, floors, and steps.

The **chief causes** of rock decay are **air, water, plants,** and **animals.** Of these, air and water are the most important. Both air and water produce **physical** changes (§ 103), by wearing off and carrying away rock material; they also produce **chemical** changes, in that they alter the nature of the minerals of the rock. Thus the carbon dioxide and water of the air act as an **acid** (**carbonic acid**; § 247) in decomposing feldspar, limestone, and the cementing material of many rocks. As a result the rocks crumble. Air can also **oxidize** certain rocks, as it "rusts" iron.



Photograph by Geo. D. Fuller.

FIG. 269.
A sand dune being carried into the Grand Calumet River by the wind.

The **air,** as wind, moves dust; it can also move sand and soil (Fig. 269). A strong wind carrying sand is a **cutting** tool, as a sand blast is (§ 11).

Water, as **ice,** is a very important cause of rock decay. Most rocks are porous, and all have cracks. When water freezes in the cracks, its **expansion** (§87) forces the rock apart. Because water is denser than air, it can carry greater loads. Mountain torrents transport great boulders; a river carries small gravel, sand, and the fine particles that produce mud and clay. A river carrying sediment scours out its bed, just as a wind carrying sand sculptures rock.

Plants act chemically, producing acids which attack rock; they also act as **machines,** forcing rocks apart, as when a tree root breaks a sidewalk.

The **total effect** which the **down-tearing** agencies, including the sea, produce upon the earth's solid crust is called **erosion.**

284. Kinds of Soil.— If we classify soils as to the way in which they were **formed,** there are **two** classes: (1) those that were formed where we find them (**sedentary** soils); and (2) those which have been moved to their present location (**transported** soils).

We have learned that mantle rock and soil are weathered bed-rock. In the United States the soil is related to the bed-rock in two entirely different ways. In the Southern states (except in the Gulf Region) the soil and the bed-rock which it covers are of the **same material.** As we dig down, we find the rock less and less decayed. If there are boulders, they are simply harder parts of the bed-rock, which have decayed more slowly. This soil was undoubtedly formed where it now lies, by the weathering of the bed-rock. It is a sedentary, or **residual,** soil.

Over the remainder of this country the soil is usually quite different from the bed-rock under it. We may find a sandy soil resting upon limestone, or clay upon sandstone. The boulders (they are often very numerous) are of materials that do not exist in the bed-rock of the region at all. This soil must have been **transported.**

What agents transported the soil? They must have been Nature's "common workmen": chiefly **water, ice,** and **air.** Soils deposited by water are **alluvial** soils. Running water picks up material at one place, and deposits it at another (§§ 282 and 283). We do not need to study rivers to learn this; we can see such action during every rain. On the slopes the **rills** that pour down wear away the soil and form channels. The transported material is deposited when the water's velocity is checked at the base of the slope. The deposit usually takes the form of the Greek letter Δ (our D), and is called a **delta.** The Gulf Region is largely the delta of the Mississippi. Why are alluvial soils usually very fertile?

The peculiar soil of the Northern states and of southern Canada was formed and transported by **ice,** and is called **glacial** soil. A great, moving ice sheet once covered the land, as the interior ice sheet now covers Greenland. The ice brought fragments of igneous rock from the North and left them in the United States. It ground rocks into soil. It pushed before it great masses of clay filled with stones (**boulder clay,** or **till**). It carried other material on its back. It cut down hills and filled valleys. Finally, by means of stones frozen into its base, the ice sheet marked the bed-rock with **grooves,** so that we can trace clearly the direction from which it came. In the North Central states the ice sheet extended about as far south as the Ohio and Missouri Rivers. The **corn belt** contains glacial soil. The time during which the ice lasted is the **Glacial Period.**

A third kind of soil was brought by the **wind,** and is called **aeolian** (ē-ōl′ĭ-ăn) soil. A sand dune (Fig. 269) is an example. Many soils of the western prairies are aeolian. The **loess** (lō′ĕs) or "bluff" soil found along the Mississippi and Missouri Rivers, and in China, was probably formed by both wind and water. It is quite fertile.

285. What Soil Contains.— We have studied soil as weathered rock. Usually it is a mixture of sand and clay, and is called **loam.** To be fertile, a soil must also contain organic matter, either added, or formed by the growth and decay of plants. We see such matter in the top-soil of a forest. Growing plants need organic matter as a food; but it is more than a food, for it acts upon the minerals of the loam, and helps prepare them, too, for the use of the plant. The plant gets its food, not from the solid soil, but from that portion of it which is **in solution;** hence a soil must contain sufficient **water.** A fertile soil must also contain **air** for the respiration of the roots and underground stems (§ 71) of plants, as well as for that of the soil's **inhabitants,** such as earth worms, bugs, bacteria, and fungi (§ 32). One who studies the soil carefully learns that it is not a dead, mineral mixture, but a world of life and activity. He also realizes that a fertile soil required centuries for its development, and that if it is destroyed, it cannot be restored in a year or two. Every farmer needs to know what his soil contains, what it lacks, for what crops it is suited, and how it ought to be handled to give him the best possible crops without losing its fertility. Moreover, since all of us, no matter where we live, depend upon soil products, we are all interested in the soil and its welfare. *The real wealth of our country is the fertility of its soil.*

286. Structure of Soil.— We have already classified soils as to the way in which they were formed (§ 284); we can also group them according to the **size and arrangement** of their particles. Since the soil must contain water and air for the plant's use and for the living creatures present, the **size** of the soil particles, and the distance they are apart, are of great importance. Beginning with the soil having the largest particles, we may classify soils as **gravel, sand, silt,** and **clay** soils. The degree of fineness or coarseness is the **texture** of the soil. Dry clay particles form a dusty powder, like flour.

From a soil of the right degree of porosity a plant can usually draw water, even in dry weather, because the water can be brought up, by capillary action (§ 119), from considerable depths. The freezing and thawing of water in the soil, the amount of organic matter, the amount of moisture present when the soil is plowed or cultivated, all have important effects upon the physical condition, or **tilth,** of a soil.

Lime and limestone, which are often used as fertilizers (§ 293), have important effects on the arrangement of soil particles. In a very sandy soil the particles are too far apart to make a good soil; the soil is too porous. Lime and limestone help to cement the separate grains together (§ 280), forming a less porous soil. While these materials make a sandy soil **less** porous, they make a clay soil **more** porous; for they separate the particles of clay, which are too close together, by forming **nuclei,** or centers, around which the particles can collect. The soil particles are thus made larger, and the soil more porous.

287. Water of the Soil.— We have seen what happens to the water that falls as rain (§ 86); what the soil cannot absorb and hold, flows off through the drainage channels of soil and rock. This is **free water.** The water which is useful for plant growth is the part **remaining** in the soil in the form of a thin **film** surrounding each soil particle. As the soil particles at the surface lose their film water, more rises from below, by **capillary action.** The film water, during its contact with the soil particles, dissolves some of the soil material; and the root hairs take up this **soil solution** for the use of the plant. The amount of water removed from soil by growing plants is enormous. Thus, in order to produce a pound of potatoes, the potato plant must take up about 400 pounds of water.

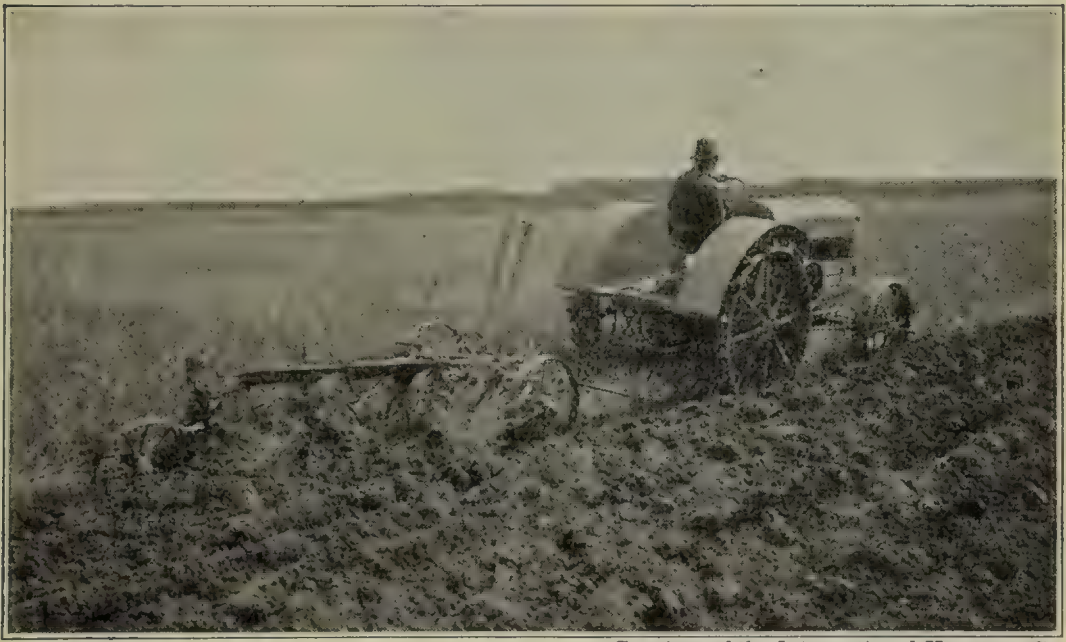
The farmer has a good deal of control over the depth in the soil at which film water shall remain. If he wishes it near the **surface,** so that it can assist freshly sown seed to germinate, he can pack the soil down with a roller. In this way he brings the soil particles closer together, and the water can rise more readily by capillary action. If he wishes to diminish surface evaporation, he cultivates the surface soil thoroughly, forming a dust mulch. The soil particles are then so widely separated that they do not provide channels in which capillary water can rise.

288. Drainage and Irrigation.— The rainfall of a region is a very important condition for farming in that region (§ 135). But the situation and structure of the soil, which give it its power to catch and retain water, and to get rid of excess water, are also important. In order to extend the area of the land he can cultivate, man has had to devise ways for **draining** flooded lands and for **irrigating** dry lands. If a soil is too wet, so that its air spaces are filled with water, plant roots and the air-using creatures of the soil are drowned. If the soil is too dry, the soil solution cannot get to the plant roots, and the plant starves and withers.

Wet farm lands are usually drained by ditches, with or without **tiles. Irrigation** is often carried out with great success in regions of low rainfall. The water that falls in the rainy season, or is released when snow melts in the mountains, is **impounded** in large reservoirs and supplied to farms and orchards when needed. The reservoir is made by the building of a dam across the outlet of a lake or across a stream. The water flowing over the dam forms an artificial waterfall, which may be used for power (§ 186).

One method of irrigation is to **flood** the soil to a certain depth and then allow the water to sink in. Another way is to use perforated **pipes** to throw sprays like rain. A third way is to use **furrows** for the water; it then soaks **sidewise** into the growing area. "Watering the garden" is irrigation. "The hose should be used to resemble rain. Give the garden a good soaking, then let it alone until it has dried out to a depth of 2 to 4 inches. Then repeat the watering. Frequent, shallow watering is wrong, as it induces shallow rooting. When the watering is neglected, the roots near the surface die, and the plants suffer. If a garden is properly watered, the roots go down some distance; if watering is too shallow, they will run along horizontally, just under the surface."

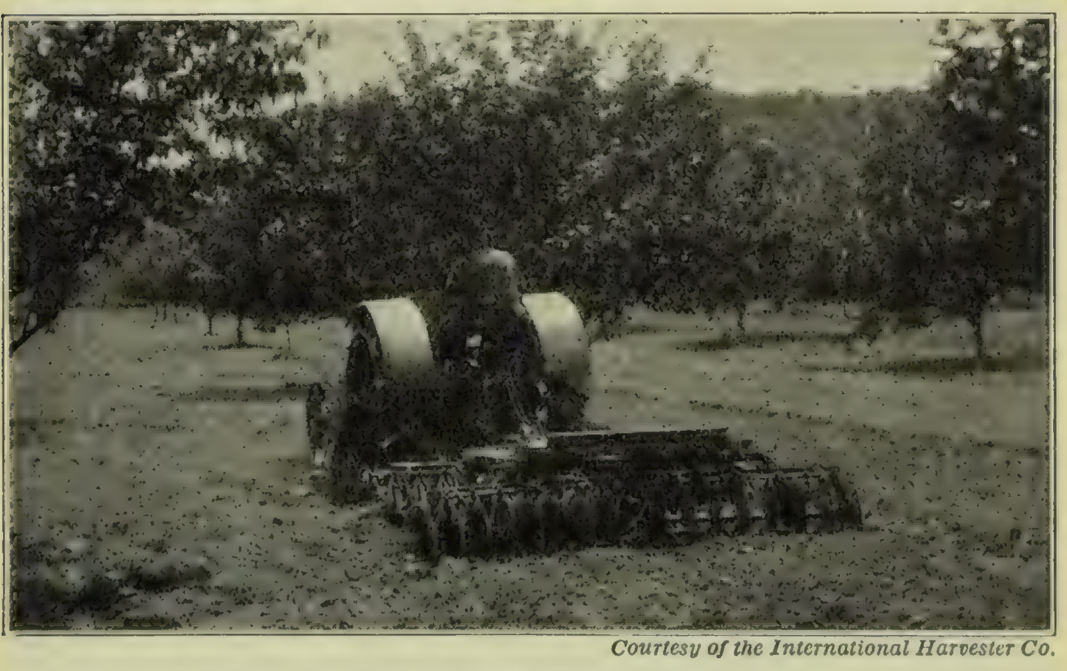
289. Tilling the Soil.— Tillage is working the soil by means of implements. They may be garden tools, such as the spade, hoe, and rake, or they may be plows (Fig. 270), cultivators, and seed-planters, drawn by horses or **tractors.** The farmer tills the soil in order to give it the right **structure** (§ 286), so that it may catch and hold water properly, and may permit plants to get their nutriment from a wide range. Tillage also "turns under" rubbish, manure, and fertilizers, and makes them part of the soil.



Courtesy of the International Harvester Co.

FIG. 270.
A three-bottom gangplow drawn by a gear-drive tractor.

A **plowshare** cuts into the soil to a certain depth, and then turns the slice of soil over upon itself in the furrow, so that its edge projects from the ground. **Plowing** loosens the soil, breaks it up, and brings to the surface new soil material for the plant. Modern methods have greatly increased the **depth** of plowing. Primitive peoples merely scratched the surface, and were able to till only a small area. **Cultivating** (Fig. 271) is shallow plowing, or stirring, of the soil, usually after a crop has begun to grow; in order that the surface may have the right **structure** (§ 286). Cultivating also destroys **weeds.** In **dry-farming,** in regions of small rainfall, especially frequent cultivating is carried on, in order that a deep dust **mulch** may be produced. This keeps the soil moisture from too rapid evaporation (§ 287).



Courtesy of the International Harvester Co.

Fig. 271.
Cultivating an orchard with a disc harrow drawn by a tractor.

290. Soil Elements.— The life of plants requires at least 10 **elements,** 7 of which reach the plant only through the soil, while 3 others: carbon, hydrogen, and oxygen, come also from air and water. The 10 necessary elements are: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, iron, and sulphur. Chlorine may be necessary. These elements are all found in fertile soil. Thus potassium is a part of clay, and calcium of limestone (§ 62). Both calcium and phosphorus are parts of calcium phosphate. Nitrogen and carbon are found in the organic matter of soil.

Of the ten necessary soil elements, only 3 or 4 are commonly used up rapidly. These are **nitrogen, phosphorus, potassium,** and sometimes **calcium.** People often suppose that if **any** compounds of these necessary elements are present, the soil is fertile. This is a mistake. The elements must be in such compounds that the plant can absorb and use them. They must, for example, be in compounds that are **soluble;** for it is the **soil solution** (§ 287) that the plant actually takes up.

291. Maintaining Fertility.— The fertility, or **productiveness,** of a soil is its power to produce crops. This power depends upon the elements and physical condition of the soil, upon the water supply, and upon other conditions, such as climate. A soil that can grow corn in Iowa may be barren, as far as corn is concerned, in Labrador.

Why does a soil lose its productiveness? We can see that the first cause is the **growing of crops;** for crops are raised in order that they may take up certain soil elements and convert them into food for man and animals. This loss cannot be avoided. But there are other causes of loss that can be looked after. One of them is **improper tillage** of sloping ground. The loss from this cause is enormous, since not only soluble compounds, but also the undissolved, but light, particles of the surface soil are carried away after every rain. **Nitrogen** compounds, especially, disappear in this way; since they are easily changed into soluble form. Nitrogen also leaves a soil readily, and goes back into the **atmosphere** (§ 32), when the organic material which should remain in the soil decays too rapidly, or is destroyed by burning.

Wise tillage, as we have just learned, is one way to maintain the fertility of a soil. A **second** way is **good management.** A farm is a business, run for profit. A farm cannot pay a profit if it sells the fertility of its soil at too low a price. The crops that are sold should be those that take the least possible fertility from the farm. Crops that take much fertility, and themselves bring a low price, should not be sold, but converted into products that have a greater market value. Thus, when grains are cheap, they should be used as cattle food, if possible, because the price received for the soil fertility as meat is usually greater than the price received for it as grain. Good management requires that everything not actually sold from the farm be put back upon the land. Hence good farmers preserve carefully, and use, **manure,** the most common of farm fertilizers, in order to restore organic matter to the soil. This is an additional reason for the raising of cattle. A crop like clover, which the farmer "plows under" (§ 32), is called a **green manure.**

Dairying is profitable, not only because dairy products bring a high price, but because they do not remove much fertility. If we sell butter, for example, we are selling chiefly **fat,** composed of carbon, hydrogen and oxygen; that is, a product made out of water and the carbon dioxide of the air.

292. Crop Rotation.—Farmers once tried to restore the fertility of a worn-out field by plowing it, and letting it lie unused, or **fallow,** for a year or two. This, however, is an expensive method; for the field is bringing in no return. It is much better not to allow a field to wear out, but to maintain its fertility by **rotating,** or changing its crops. Thus, instead of growing corn on a given field year after year, the farmer can grow corn, wheat, and timothy in succession, coming back to corn every third year.

The rotation of crops depends upon the fact that different crops remove different amounts of the soil elements. Grains, such as wheat, take up much phosphorus; timothy takes up little phosphorus. Corn is exhausting to a soil, for it removes much of all three of the elements nitrogen, phosphorus, and potassium. If the crop is changed at intervals, a soil that has lost much of a given element has time to recover and to get back enough of that element for the plant's use.

Rotation has other good results. The **root systems** of plants are different; hence one plant often breaks up the ground for another. If one plant grows for several years in a field, its **diseases** or **insects** often gain a strong foothold. When the crop is changed, the new plant is usually not affected by the diseases or insect pests of the other. Some **weeds** grow readily in fields containing a certain crop, and not so easily along with other crops. Thus the cockle is a weed that grows with wheat, but not with corn. If the crop rotation is wheat, grass, corn, the weed is killed before the next wheat crop.

293. Commercial Fertilizers.— We have learned of several ways of maintaining soil fertility: proper tillage, good management, the use of manure, and crop rotation. An additional way is to use a **commercial fertilizer** containing the soil element which crops are using up: nitrogen, phosphorus, or potassium. A **complete** fertilizer contains all three.

The **potassium** compounds needed by the soil can be obtained from wood ashes, if these are to be had (§ 252), or from deposits found in France and Germany. Some lavas yield a potassium fertilizer.

Phosphorus is sold, as a fertilizer, in the form of **bone meal** or powdered **rock phosphate.** Rock phosphate is found in South Carolina, Florida, and Tennessee. There is also a large deposit in the group of states: Utah, Wyoming, Montana, and Idaho.

Calcium phosphate dissolves very slightly, so the manufacturers of fertilizers often change it into **acid calcium phosphate,** which is more soluble, by treating it with sulphuric acid (§ 246). The acid phosphate is called "superphosphate." Sulphuric acid and calcium phosphate also produce the fertilizer called **land plaster,** which contains much calcium sulphate, or **gypsum.**

Nitrogen is an important part of farmyard manure. Two commercial sources of it are cottonseed meal and fish-scrap meal. The waste materials of stockyards: blood, and scraps of meat and bone (tankage) are rich in nitrogen, and are converted into fertilizer. **Nitrates,** obtained from the western coast of South America, are also important sources of nitrogen. The **nitrifying bacteria** of the soil oxidize much of the nitrogen of fertilizers to **nitrates.**

One of the causes of loss of productiveness of a soil is that the soil becomes **acid,** or "sour." Clover, alfalfa, and many other crops grow very poorly upon acid soil. The cure is a **basic** substance, such as **lime** or **limestone,** which neutralizes the acid, and makes the soil "sweet" (§ 249).

294. Summary.— The earth's crust contains **mantle rock** and **bed-rock.** Exposed bed-rock is an **outcrop.** **Soil** is the upper part of the mantle, used for growing crops. The **subsoil** is below the soil.

Rocks are **stratified, unstratified,** and altered, or **metamorphic.**

Stratified rocks were formed, as deposits, under water.

Unstratified, or igneous, rocks are found **under** all rocks, in the cracks of stratified rocks, and as overflows over stratified rocks. **Metamorphic** rocks are altered stratified rocks.

Soil is made by the weathering, or decay, of rock.

Erosion is the down-tearing of the earth's solid crust.

Two classes of soils are **sedentary** and **transported** soils.

Soil contains decayed rock, organic matter, water, air, and living things.

Texture of soil depends upon the **size** of soil particles; **structure,** upon the **arrangement** of particles.

Water passes up through a soil by **capillary action.**

Irrigation adds water to a soil; **drainage** removes water.

At least **10 elements** are needed by plants.

Fertility, or productiveness, is crop-producing power. It is maintained by wise tillage, good management, crop rotation, and by manure and other fertilizers.

295. Exercises.— 1. Which will rise in temperature more rapidly when exposed to the sun, a wet soil, or a dry one? See § 98. Which will cool more rapidly after sunset?

2. Which absorbs heat more readily, black or white soil?

3. Define these terms as applied to soil: heavy, fallow, productive, alluvial, glacial, sour, sedentary, and loam.

4. How do freezing and thawing prepare soil for crops?

5. What advantages result from organic matter in soil?

6. In sweetening a soil with wood ashes what necessary plant food are we adding at the same time?

7. What is the economy of using the cream of milk for butter, and feeding the skimmed milk to calves or pigs?

8. What is the economy of having birds on a farm?

9. How do pebbles become round? If such pebbles are found far from a body of water, what do you conclude?

10. Suppose the rock under Niagara Falls (Fig. 267) were suddenly to become soft shale; what would be the effect? Have the Falls always been where they are?

296. Projects.— 1. Prepare a paper on the making and uses of concrete, including reinforced concrete.

2. Prepare a paper on the formation of coal.

3. Prepare a paper on the Glacial Period.

4. Prepare a paper on the manufacture of china, earthenware, stoneware, and bricks.

5. Collect several samples of coal, and show their structure to the class, also how they burn.

6. Make a collection of pebbles, and show the class how to decide which is limestone, sandstone, or granite.

7. Make a collection of several building stones, and describe their qualities and uses.

8. Collect or borrow several fossils, and describe them.

9. Show the class how we determine hardness. See Appendix XI.

10. Collect a bottleful of weathered rock from the base of a boulder or cliff, and show it to the class.

11. Visit a railroad cut or a house excavation and bring some of its soil, subsoil, and bed-rock, if possible, to class.

12. Collect at least 6 kinds of soil, including clay, clay loam, sandy loam, sandy soil, dark soil, and loaf mold.

13. Sketch, or photograph, a delta formed in a rain.

14. Show the class the litmus test for an acid soil. Use a stiff mud of the soil to be tested.

15. Make a collection, in stoppered bottles, of commercial fertilizers, and describe their constituents and uses.

16. Arrange a debate on the question: Resolved, that it is economy to burn the stubble of the farm.

297. References.— BENNETT: *The Soils and Agriculture of the Southern States.* CROSBY: *Common Minerals and Rocks.* HOPKINS: *Elements of Physical Geography.* HOPKINS: *Soil Fertility and Permanent Agricultnre.* INTERNATIONAL HARVESTER CO.: *Bulletins.* WATERS: *The New Agriculture.* WHITSON AND WALSTER: *Soil and Soil Fertility.* WIDTSOE: *Dry Farming.* U. S. DEPARTMENT OF AGRICULTURE: *Bulletins.*

CHAPTER XVII

OUR FOOD

298. Why We Need Food.— Do you want to live long and in good health? This has always been one of the keenest desires of mankind. So it is important for us to know that the scientific study of foods has, within the last few years, gone far toward bringing good health and long life within the reach of most of us. People used to think that all we need to ask of a food is that it shall taste appetizing and satisfy our hunger. Science tells us that this is not enough. Scientists have made the discovery that many diseases are caused by some fault or lack in the food of the sufferer, and can be cured by correct feeding. They have also discovered that most people who are weak and languid are so because they are not eating enough of certain foods which the body needs. Why do some families constantly catch colds and other diseases, while other families are rarely sick? We often find the cause in differences of food habits, as a result of which the members of one family have a **good resistance** to disease, while those of another family have a **poor resistance.**

If we think for a moment of the structure of the body, we shall see that, like an automobile, or a steam engine, or a watch, it is built according to a plan, and that each part of its wonderful mechanism is made out of certain materials, and given just the right size, shape, and strength.

To learn the composition of our bodies, we go to the chemist. He tells us that the bodies of man and of animals are made up of the elements carbon, hydrogen, oxygen, nitrogen, calcium, phosphorus, potassium, sulphur, sodium, chlorine, magnesium, iron, iodine, fluorine, and silicon. How does this list compare with that of soil elements needed by plants? See § 290. Although the last three elements are in very minute quantities, one of them, at least, the element iodine, is of great importance (§ 301). These 15 elements are combined in the material of living cells (§ 353), and the cells, united by a wonderful plan, make up the human body.

What does food do for us? If we want to take a trip in an automobile, we are careful to fill the gasoline tank before we start. When we travel across the country on a train, the train stops from time to time to take on coal or water. If automobiles and trains are to run, they must be fed with gasoline, or coal, or other fuels. It is the same with our bodies. If we want to work and move about, our bodies must have something to burn in order that they may have the necessary energy. The body does not burn gasoline or coal; it burns food. The food which we eat is oxidized as the gasoline and coal are, and yields, as they do, heat and energy (§§ 50, 51, and 71).

We must notice, however, that there is one important difference between the human engine and the steam or gasoline engine: the human engine is not built in its final form; it has to **grow.** It wears out, too, and has to make its own repairs. Some processes that go on in the body also require special foods to regulate them. Therefore foods are needed in the human engine for two main purposes: (1) to give us energy (such foods must be "burnt," or oxidized, in the body); (2) to supply the materials for growth and repair, and for regulating the body. All our foods may be put into one of six classes:

1. **Carbohydrates.**
2. **Fats.**
3. **Proteins.**
4. **Minerals.**
5. **Water.**
6. **Vitamins.**

299. Food for Energy.— All foods of the first three classes give us energy when oxidized, but the most desirable fuel foods are the carbohydrates and fats. Carbohydrates include starches and sugars (§§ 66 and 315). Both carbohydrates and fats are compounds of carbon, hydrogen, and oxygen. When they are used in the body, they combine with more oxygen (obtained through the lungs, § 71) until the carbon and hydrogen are completely

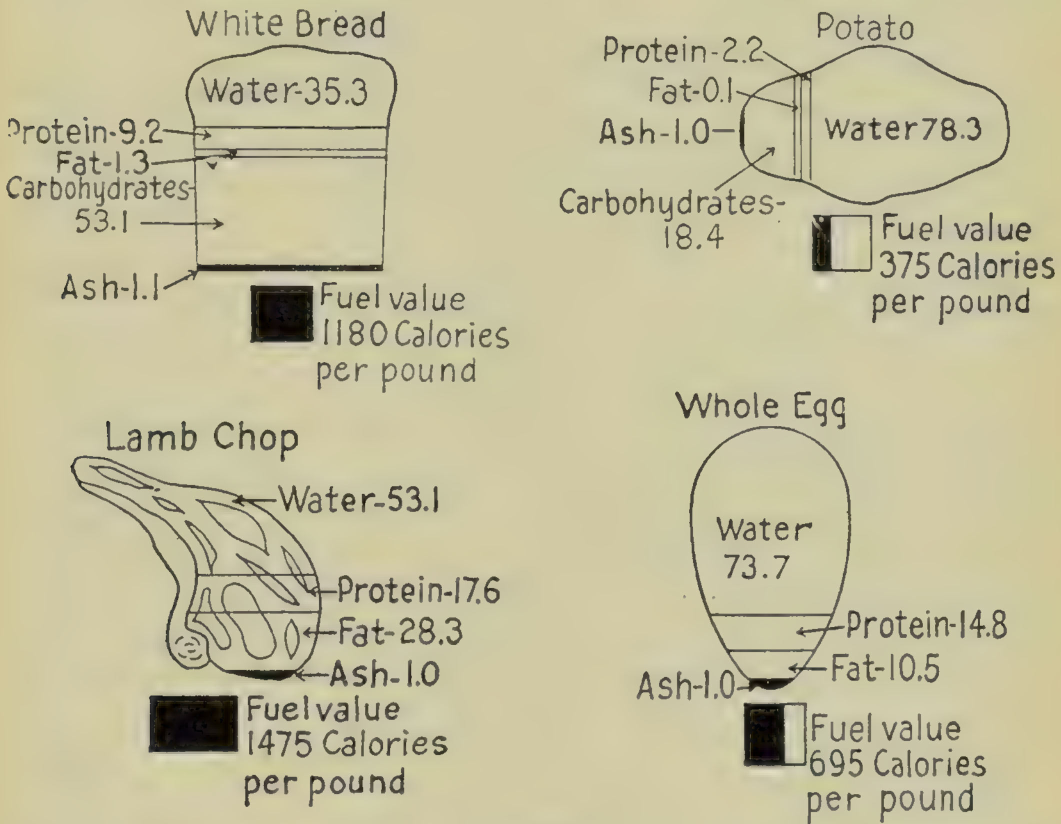


FIG. 272.

The food materials present in four common articles of diet. (From the charts prepared by C. F. Langworthy for the U. S. Department of Agriculture.)

oxidized. What products are formed? This process of oxidation is accompanied by heat and the production of energy; as a result of it we can keep warm (§ 50), and have the ability to work and play. Why are we hungry after a game of tennis or hockey or football? Why are we warm?

The **carbohydrates** are found almost entirely in vegetable foods. Except in milk, only traces of them are found in any animal food. All grains, such as wheat, rye, oats, barley, corn, and rice, and products made from them, are known as **cereal** foods. They are good sources of carbohydrates. Potatoes and starchy vegetables are excellent sources, too.

The **fats,** the other great class of energy producers, are found in both vegetable and animal foods. They include the **oils** (§ 252), such as olive oil, cottonseed oil, corn oil, and peanut oil, and the solid fats, such as beef suet, lard, tallow, and butter. The fats have a larger proportion of carbon and hydrogen than the carbohydrates, and therefore produce much more heat when oxidized. A pound of fat generates 2¼ times as much heat as a pound of sugar or starch.

If we eat carbohydrates and fats in larger quantities than our daily needs, the surplus is stored in the tissues as fat (§ 368). A little fat gives the body a reserve of fuel to be used in time of need, and is desirable. Too much stored fat is not desirable, as it interferes with the activity of the muscles (§ 357), and gives added labor to the heart.

300. Food for Building and Repair.— Every living cell and organism contains **nitrogen** (§ 32); therefore foods which contain nitrogen are needed to build new cells and to repair old ones. Such foods (nitrogenous foods, or proteins) contain carbon, hydrogen, and oxygen, as well as nitrogen, and if an excess of protein is eaten, it can be oxidized to furnish energy, just as carbohydrates and fats can. However, if proteins are used as fuel, their nitrogen is wasted (§§ 32 and 291), and even worse than wasted, for it forms compounds which the body has a hard time getting rid of. For that reason, and also because the nitrogen foods are usually more expensive, it is wise to eat only as much of them as the body needs for growth and repair, and to depend upon carbohydrates and fats for heat and energy. Nitrogen cannot be stored in the body as sugars and fats can; hence we need to get a supply of it, daily, in our food, in order to make up for what is used daily in the cells of the body.

Lean meat, including the meat of poultry and fish, is the most common food of this class. Milk, cheese, and eggs are other valuable foods which supply nitrogen; it is also found in large quantities in such vegetable sources as nuts, peas, beans, and lentils. Grains of all kinds contain protein, but not in amounts large enough to supply our daily need for nitrogen, unless we eat them in very large quantities.

Proteins in the different foods differ not only in **quantity** but also in **quality.** The proteins of peas and beans, and some others from vegetable sources, while they are very useful, are called "incomplete." Gelatine, too, furnishes an incomplete protein. In order that we may furnish proper nitrogenous food to the body, it is wise to add some good **animal protein,** such as is found in milk, cheese, eggs, or meat, to the cereal and vegetable foods which form the bulk of our diet. Doing this will help us to be sure that our cells are being properly built and repaired.

301. Need of Minerals in Food.— The minerals found in most foods, and to some extent in water, are of very great value. We could not live without them, and we do not live in health if we do not give them to the body in sufficient quantities. They are often called the body regulators.

Sulphur is needed for cell building, along with nitrogen. It is found in eggs and in other protein foods. We are likely to get enough of it in our diet without any special effort. This is not the case with phosphorus, calcium, iron, and iodine.

Phosphorus, too, is a cell-builder; with calcium it gives solidity and strength to the bones and teeth. If we do not have enough of it in our food, our bones are weak, and our teeth decay. The best source of phosphorus is **milk.** Other good sources are meat, eggs, cheese, string beans, whole cereals, and potatoes.

Calcium is another cell-builder. It is particularly needed as the partner of phosphorus in making good bones and teeth. The best source of calcium is **milk,** although it is also found in some vegetables and fruits. For the appearance of bones when their minerals are removed, see § 69, projects 2 and 3.

Iron is necessary for the making of **red blood-corpuscles,** which contain the materials by which oxgyen is carried from the lungs to the cells (§ 378). When iron is lacking in the diet, the disease **anemia** (a-nē′mĭ-a) lays hold of the body. Many children are pale and seem dull and lifeless, because they are suffering from a lack of iron in their blood. The body cannot digest nails or a bar of iron; we must get our iron by eating foods which are rich in it. The yolks of eggs are rich in iron; so are green vegetables, especially spinach. Graham bread, potatoes, raisins, figs, prunes, beans, and peas have iron in quantities we can measure.

Iodine is of importance to us, although we need very little of it. It is used in the cells of the **thyroid** (thī′roid) **gland** (§ 359), located in the throat. This gland is a small, but necessary, part of the human machine. If it lacks iodine, it enlarges, and a goiter appears, and serious internal disturbances may occur. Iodine is found in water and plants along the sea coast, in sea fish, and in impure sea salt. Inhabitants of countries near the sea coast usually get enough iodine in their food. Districts far from the sea lack iodine in soil and water and therefore in food, so that their people and animals are likely to suffer because they do not get enough iodine. It is for this reason that iodine is regularly given to school children by health officers in many inland districts of the United States.

We secure a plentiful supply of **sodium** and **chlorine** in **common salt,** which we use daily to season food (§ 102).

Foods Supplying Protein		Foods Supplying Iron		Foods Supplying Phosphorus	
lean meat	(Grains and vegetables supply some)	spinach	tomatoes	milk	turnips
fish		egg yolk	potatoes	fish	string beans
eggs		string beans	carrots	eggs	whole grains
oysters		lean meat	whole wheat	lean meat	peas
milk		lean fish	oatmeal	spinach	potatoes
cheese		peas	raisins	cauliflower	berries
peas		asparagus	prunes	lettuce	
beans		lettuce	figs	celery	
peanuts		cauliflower		tomatoes	

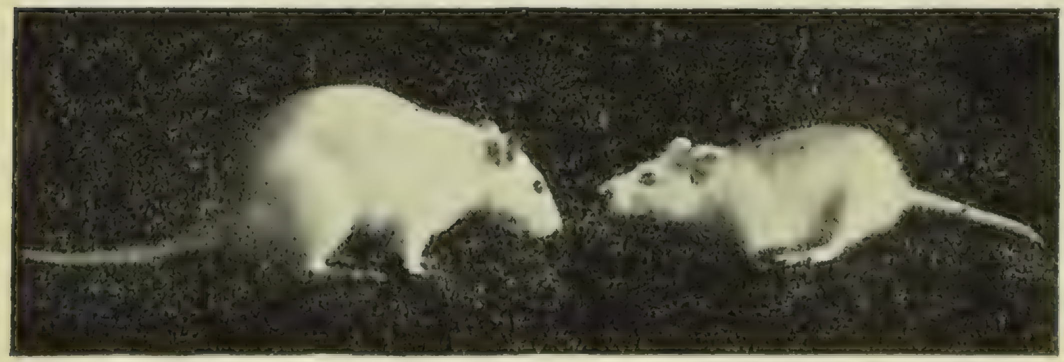
NOTE: Other foods furnish a smaller supply. Those listed are the richest.

302. Need of Water in the Diet.— Every food contains some water, and some foods, such as milk, juicy fruits, and vegetables, are largely water (§ 86). Water is the most important thing in the diet. Man can live without food for many days, because his body can use up part of its cells to feed the others (§ 368); but water is absolutely necessary, if life is to be preserved long. Water is used in building up the tissues, in carrying them supplies, and in carrying away wastes. What proportion of the body is water?

Drinking water at meal-time is not harmful, if the water is not so cold that it retards digestion (§ 359), and if we do not "wash down" half-chewed portions of food with it. A drink of water a little while before eating is of great benefit in preparing the digestive organs for receiving food. We should drink from 4 to 6 glasses of water every day, besides what we get in foods, such as milk and soup.

303. What Vitamins Do for Us.— Do you think that hearing by radio seems like magic? The work of **vitamins** (vĭt′ă-mĭns) seems like magic, too. Scientists have only recently found that they exist, and no one, as yet, knows what a vitamin looks like. We recognize their presence by what they do in the body, although they are present in it in very small quantities. Investigators have found out that vitamins are just as necessary for maintaining life as carbohydrates, proteins, and minerals are.

How can scientists discover all these facts about foods? They may suspect, from their observation of children or adults, that some so-called diseases or bodily weaknesses are really caused by faulty diet; but how can they find out the truth? They cannot, as a rule, carry out complete food experiments on people, for two reasons: (1) no one wishes to peril the health or lives of human beings; (2) people are so long-lived that the full effects of a lack in diet may not be plainly visible for several years. So scientists experiment with animals which mature in a few months, and have short lives. White rats, because they can live on such foods as people eat, are good animals for food experiments (Fig. 273); guinea pigs and pigeons are frequently used.



Courtesy of Dr. Mary Swartz Rose.

FIG. 273.

Brothers of the same age, one raised on bread and milk, the other on bread and meat. The one that received milk had plenty of vitamins A and B; the diet of the other was deficient in vitamins.

Three vitamins have been discovered thus far: vitamins **A, B,** and **C.** A fourth vitamin, sometimes called "X," is now being investigated.

Vitamin A, also called fat-soluble A, is found in milk and egg yolk, in cod-liver oil, and in spinach and other leafy, green vegetables. It is not found in vegetable oils. If children do not have enough vitamin A in their food, they do not grow, and so are stunted and weakly. They are not able to fight off disease germs (they have a "poor resistance," § 298), and so "catch" colds and even tuberculosis (§ 80). A lack of vitamin A often shows itself in weak and swollen eyes. During the World War, children living in countries where the milk supply (the most available source of vitamin A) was low, developed this eye trouble. It was promptly cured when they were given whole milk, with its rich store of vitamin A.

Vitamin B, also called water-soluble B, is found in whole grains and whole-grain products, such as oatmeal, graham flour, and unpolished rice. It is also found in cabbage, tomatoes, beans, peas, potatoes, and in other vegetables and fruits, likewise in milk, eggs, liver, kidney, and yeast. It is not found in what we call "refined" foods. Refined foods are products which have been milled or worked over in factories to take away some of the coarse, strong-tasting parts. White flour, starch, white rice, finely milled cornmeal, lard, vegetable and nut fats, sugars, and muscle meat are refined foods, and are all lacking in vitamin B. Vitamin B is destroyed by alkalies (§ 248), and by baking soda.

The disease beri-beri, common in oriental countries in which poor people depend largely on polished rice for food, is due to a lack of vitamin B, and is cured when unpolished rice is substituted for the refined rice. Beri-beri is not confined to oriental countries, but has been found wherever people have lived overmuch on refined foods. Loss of appetite, slow growth, sometimes even paralysis, result from a lack of vitamin B.

Vitamin C, also called water-soluble C, is found most abundantly in fresh fruits and vegetables. Oranges, lemons, grapefruit, tomatoes, cabbage, lettuce, spinach, and potatoes are all good sources. Vitamin C is easily destroyed by long cooking, although cabbage and acid fruits and vegetables (like berries and tomatoes) can be cooked a short time (perhaps 15 minutes) without great injury to the supply of vitamin C. Vitamin C is needed **daily** by the body; this is the reason why all rules for a wise diet say that we should eat some fresh, uncooked fruit or vegetables **every day.** Sore, swollen, bleeding gums, and teeth that are poor and soft, are signs of a lack of vitamin C. What we call "spring fever" may be due to a lack of vitamin C.

Vitamin C is often called the **anti-scorbutic** (skŏr-būt′-ĭk), or anti-scurvy, vitamin, because the lack of it causes the serious disease, **scurvy.** This disease often afflicts people on long sea voyages, when their stores of fruit and vegetables are gone. It is prevalent sometimes in asylums in which people are fed too cheaply on defective foods. Babies fed on an artificial diet often have scurvy. Can you see why doctors tell mothers to feed a little diluted orange juice or tomato juice to infants?

Food experts are now investigating the so-called **vitamin X.** It is found in milk fat and cod-liver oil, and is a cure for the disease, **rickets.** This disease is much more common than we generally realize, for most adults show some sign of having had the disease in infancy. The disease is evident in bony deformities, such as bow legs, enlarged knees or other joints, slow teething, and other signs that something is wrong with the process of bone making. Modern physicians are giving cod-liver oil to infants almost from birth to prevent rickets.

FOODS VALUABLE FOR VITAMINS

Vitamin A		Vitamin B		Vitamin C	
milk	oranges	whole cereals	tomatoes	oranges	turnips
cream	lemons	yeast	cabbage	tomatoes	berries
butter	liver	milk	green leaves	spinach	pineapple
cheese	kidneys	liver	parsnips	onions	potatoes
eggs	cabbage	kidneys	onions	cabbage	other fresh fruits and vegetables
cod-liver oil	carrots	beans	peas	lettuce	
green leaves, such as spinach and lettuce	string beans	oranges	potatoes	peas	
	tomatoes	lemons	turnips	lemons	
		grapefruit	nuts	grapefruit	

304. How Much Food Do We Need?— We have learned the reasons why carbohydrates, fats, proteins, minerals, water, and vitamins are needed in our diet. Now we must consider the very important matter of how much of each class we require each day. Can we measure it?

We have learned that the unit of **heat quantity** is the **calorie** (§ 51). Since food, when oxidized in the body, yields **heat,** we can measure the fuel value of food in terms of calories. For convenience we are likely to compute it by the hundred calories, rather than by single calories. The calorie used is the **large calorie** (Cal.), the amount of heat required to heat 1 **kilogram** (1000 g.) of water through one centigrade degree (see Tables XII and XIII, Appendix).

A DAY'S FOOD FOR A BOY OF FOURTEEN
With Its Fuel Value

BREAKFAST		Calories
banana	1 large	100
oatmeal	1 cup	100
milk	1½ cups	250
toast	4 slices white bread	160
butter	2 tablespoons	200
boiled egg	1	70
sugar	1 tablespoon	50
TOTAL		930
LUNCHEON		
macaroni and cheese	1 cup	200
graham bread	4 slices	133
butter	1½ tablesp'ns	150
cocoa	4/5 cup	200
canned peaches	2 halves and juice	100
molasses cookies	3	100
TOTAL		883
AFTERNOON LUNCH		Calories
graham bread	3 slices	100
butter	1 tablespoon	100
TOTAL		200
DINNER		
Swiss steak	2 slices	200
mashed potatoes	⅞ cup	200
spinach with egg	4/5 cup	100
tomato salad	1 serving	140
bread	4 slices	200
butter	2 tablespoons	200
brown betty	1 cup	300
milk	1 cup	170
TOTAL		1510
TOTAL FOR THE DAY		3523

The amount of food a person needs can be worked out, quite accurately, from his age, size, and activity. Children need more food, in proportion to size, than adults, because they are growing. A child two years old, weighing 30 pounds, needs about 40 large calories per pound of body weight, or 1200 calories a day. A normal child from 8 to 12 years old needs 32 to 35 calories a pound; the larger amount, if very active. Girls of high-school age need from 2200 to 2600 calories a day, or even more, if a girl is very active and athletic. Boys of the same age require from 2800 to 4000 calories, or more, a day. Women need from 1800 to 3000 calories a day, depending on age, activity, and

WEIGHT—HEIGHT—AGE TABLE FOR GIRLS

By permission of The American Child Health Association

Height Inches	5 Yrs.	6 Yrs.	7 Yrs.	8 Yrs.	9 Yrs.	10 Yrs.	11 Yrs.	12 Yrs.	13 Yrs.	14 Yrs.	15 Yrs.	16 Yrs.	17 Yrs.	18 Yrs.
38	33	33												
39	34	34												
40	36	36	36											
41	37	37	37											
42	39	39	39											
43	41	41	41	41										
44	42	42	42	42										
45	45	45	45	45	45									
46	47	47	47	48	48									
47	49	50	50	50	50	50								
48		52	52	52	52	53	53							
49		54	54	55	55	56	56							
50		56	56	57	58	59	61	62						
51			59	60	61	61	63	65						
52			63	64	64	64	65	67						
53			66	67	67	68	68	69	71					
54				69	70	70	71	71	73					
55				72	74	74	74	75	77	78				
56					76	78	78	79	81	83				
57					80	82	82	82	84	88	92			
58						84	86	86	88	93	96	101		
59						87	90	90	92	96	100	103	104	
60						91	95	95	97	101	105	108	109	111
61							99	100	101	105	108	112	113	116
62							104	105	106	109	113	115	117	118
63								110	110	112	116	117	119	120
64								114	115	117	119	120	122	123
65								118	120	121	122	123	125	126
66									124	124	125	128	129	130
67									128	130	131	133	133	135
68									131	133	135	136	138	138
69										135	137	138	140	142
70										136	138	140	142	144
71										138	140	142	144	145

When taking measurements, remove the child's outdoor clothing, shoes, and coat. Take heights with a square consisting of two flat pieces of wood joined at right angles (a chalk box will serve). The child is placed in a good erect position, with heels and shoulders against the wall or wide board, upon which has been marked or pasted an accurate measure. Age is taken to the nearest birthday.

height. Men need from 2200 to 4000, or more, if engaged in very hard labor.

The only way by which an adult can tell whether he is getting the proper amount of food, or not, is to find out the correct weight for his age and height, and to determine whether he is underweight or over-

WEIGHT—HEIGHT—AGE TABLE FOR BOYS

By permission of The American Child Health Association

Height Inches	5 Yrs.	6 Yrs.	7 Yrs.	8 Yrs.	9 Yrs.	10 Yrs.	11 Yrs.	12 Yrs.	13 Yrs.	14 Yrs.	15 Yrs.	16 Yrs.	17 Yrs.	18 Yrs.	19 Yrs.
38	34	34													
39	35	35													
40	36	36													
41	38	38	38												
42	39	39	39	39											
43	41	41	41	41											
44	44	44	44	44											
45	46	46	46	46	46										
46	47	48	48	48	48										
47	49	50	50	50	50	50									
48		52	53	53	53	53									
49		55	55	55	55	55	55								
50		57	58	58	58	58	58	58							
51			61	61	61	61	61	61							
52			63	64	64	64	64	64	64						
53			66	67	67	67	67	68	68						
54				70	70	70	70	71	71	72					
55				72	72	73	73	74	74	74					
56				75	76	77	77	77	78	78	80				
57					79	80	81	81	82	83	83				
58					83	84	84	85	85	86	87				
59						87	88	89	89	90	90	90			
60						91	92	92	93	94	95	96			
61							95	96	97	99	100	103	106		
62							100	101	102	103	104	107	111	116	
63							105	106	107	108	110	113	118	123	127
64								109	111	113	115	117	121	126	130
65								114	117	118	120	122	127	131	134
66									119	122	125	128	132	136	139
67									124	128	130	134	136	139	142
68										134	134	137	141	143	147
69										137	139	143	146	149	152
70										143	144	145	148	151	155
71										148	150	151	152	154	159
72											153	155	156	158	163
73											157	160	162	164	167
74											160	164	168	170	171

weight. If he is overweight, he is eating too much. If the body needs 2600 calories, and 2800 calories are eaten daily, the result is a gain of 24 pounds a year. A large slice of bread and butter, a piece of cake, or two pieces of candy a day more than is needed, will, any one of them, result in this gain. If the body needs 2200 calories, and gets 2000, what happens? If your weight is not more than 7% below the average, or not more than 15% above it, as given in the weight tables, you need not feel disturbed. Are you growing normally and gaining in weight? Girls from 12 to 16 years of age should gain 12 to 16 ounces a month; from 16 to 18 years a gain of 4 to 8 ounces is enough. Boys from 12 to 17 years are likely to gain 12 to 16 ounces a month. During the seventeenth year the rate per month is 4 to 8 ounces.

305. Our Need of Milk.— The most valuable single food on our list is milk. It is high in protein, contains large amounts of calcium and phosphorus, some iron and other minerals, and is rich in two of the three vitamins (A and B). There is no practicable way in which we can get enough calcium and phosphorus for the body, without milk. This is particularly the case with children. Experiments show that the **least** milk a child should have for growth is a pint a day, and that it does much better on 1½ pints a day; while if we wish a child to be of superior health and strength, it should have a quart a day until it has stopped growing. This should be **whole** milk, not skimmed milk, in order to provide plenty of vitamin A. Adults, too, need milk daily in order to keep bones and teeth sound, and to serve as a body regulator; a pint a day will be enough.

Milk may be taken as a drink, by itself, or it may be used on breakfast food, or it may be eaten as a part of cooked food, in milk soups, cocoa, milk toast, custard, rice pudding, and the like.

306. Diet for Health and Long Life.— We should eat each day:

(1) A **pint** of **milk.** Growing boys and girls need a quart.

(2) Two servings of **vegetables** besides potatoes. One should be **raw** (as a salad) if possible.

(3) Two or more servings of **fruit.** One should be **raw.**

(4) An **egg** each day, if possible; also a moderate serving of meat or fish.

(5) A **whole grain** product at least once a day (oatmeal, cracked wheat, graham bread, or the like).

(6) Four to six glasses of **water.**

We get enough **minerals**, if we follow the six rules (above), especially if we choose, often, vegetables rich in **iron,** such as spinach, and green beans; if we have an **egg yolk** each day; and if we don't forget to eat **whole cereals.** We get our calcium and most of our phosphorus from milk.

We get enough **protein** if we have our milk, an egg a day, and 2 to 6 ounces of meat or fish (the amount depending on our age and activity). Children under 6 need no meat at all, if they have plenty of milk and an egg a day.

We get enough **vitamins** if we have unskimmed milk, two vegetables besides potatoes, and two fruits (one raw).

If we are **overweight,** we must continue to follow the six rules, including the use of milk. We can safely cut down the amount of meat fat, rich gravies, and rich desserts, such as pie, pudding, cake, and candy. Adults who are overweight can use skimmed, instead of whole milk. If these changes do not bring the weight down to normal, we can reduce the amount of bread, potatoes, and other starchy foods. If we are overweight, we have too much fuel food.

Oranges, spinach, tomatoes, cabbage, and lettuce contain good supplies of all three vitamins, and are rich in minerals. They are so valuable that we do well to have at least one of them each day.

Tea and coffee have no food value. They are stimulants, and should not be taken by children. **Sugar** contains no minerals or vitamins, and is useful only as fuel.

307. Summary.— The body is made up of at least **15 elements,** combined in the material of living cells.

We **need** food (1) for **energy**; (2) for **growth** and repair.

Six classes of foods are carbohydrates, fats, proteins, minerals, water, and vitamins.

Carbohydrates and fats are valuable for energy.

Proteins should be used for growth and repair.

Minerals are also called body regulators.

Water is the most important thing in our food.

Vitamins are needed for normal growth and health.

The **amount** of food needed depends upon a person's age, height, and activity.

Milk is needed by both children and adults.

Diet has much to do with health and long life.

308. Exercises.— 1. What foods do we eat, if we want sound teeth?

2. Is appetite a reliable guide in choosing food?

3. How can one tell whether he is getting enough food, or not?

4. Why should we try to have fresh fruits and vegetables? How often?

5. If a child is small for its age, what may it lack?

6. What is the danger in using a large proportion of "purified" foods, such as white flour, white rice, and sugar, in our diet?

7. How does the human machine make its repairs?

8. Why should we avoid eating more than the body needs? Why less?

9. A family had, as its winter diet, fish, cabbage, potatoes, milk, and apples. Did it lack any essential foods?

10. Where do the minerals present in foods come from? The carbohydrates? The fats?

309. Projects.— 1. Make out a day's menu for yourself which follows the six rules of diet.

2. Set out 100-calorie portions of the following: orange, potato, sugar, butter, milk, graham bread, and fudge. Show the size of a 100-calorie portion of lean meat.

3. Determine if any minerals remain when bread, potato, and sugar are completely burned. Use the cover of a baking-powder can as the dish.

4. Prepare microscope slides with starch grains from different sources, and show them to the class.

5. Prepare a paper on the way in which the diet of the human race varies with the latitude.

6. Visit the markets of your neighborhood, and prepare a list of the fresh vegetables and fruits that can be purchased during the winter months.

7. Visit the markets near you, and make a list of the whole, unrefined foods that you can buy.

8. Prepare a paper upon the butter supply of your community, its source, its quality and price, and the amount of it used.

9. Prepare a survey of the milk supply of your community, its source, quality, price, and cleanliness.

10. Make a study of the amount of milk used in the families of the community, especially in those having children.

11. Prepare a paper on the methods and reasons for cooking food.

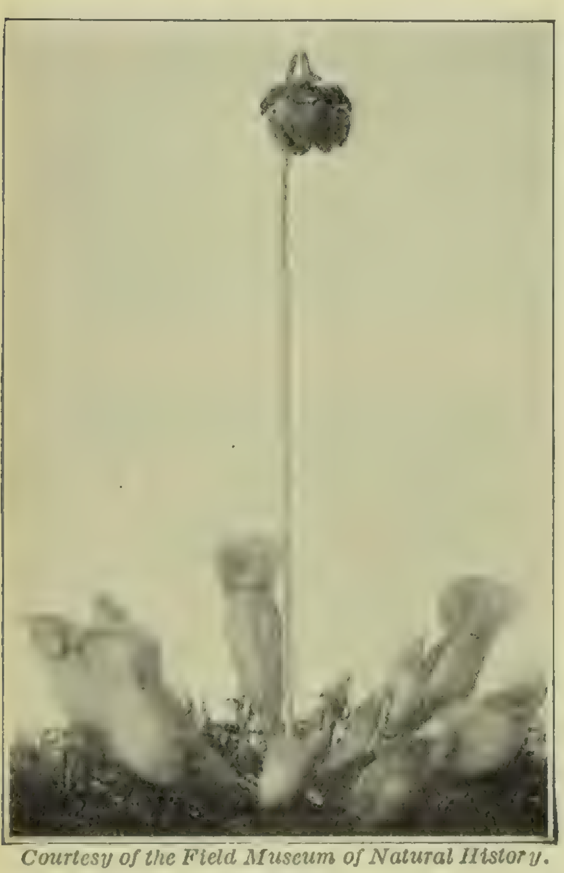
12. Make a study of the bread supply of your neighborhood, and report upon it.

310. References.— ROSE: *Feeding the Family.* WILLARD AND GILLETTE: *Dietetics for High Schools.*

CHAPTER XVIII

THE PLANT WORLD

311. Plants as Living Things.— We do not realize often enough how wonderful the plants about us are, and how marvellously they grow. Each spring we see the miracle by which fields, mountains, and forests are re-clothed with verdure; but we think little of the ceaseless, quiet activity that brings the change about. We admire the grassy carpet of a beautiful lawn; we forget that this is made up of a multitude of individual plants, each struggling to live its life according to its nature. We cannot appreciate what plants are and do, until we study them as active, living creatures, and learn something of their special structures, or **organs**, and of the definite duty, or **function,** which each performs.



Courtesy of the Field Museum of Natural History.

FIG. 274.

The leaves of the pitcher plant usually contain water in which insects drown, unable to crawl out because of the down-pointed bristles.

What a variety of creatures there is in the plant world, and how admirably they have fitted themselves for the region in which they grow! There are green plants that make their own food materials, and there are white plants, like the Indian pipe and the mushroom, that must feed upon the decaying remains of other plants. There are plants of but a **single cell** (§ 322), and there are plants with very complicated structures like the lady's-slipper and other orchids. There are even plants that carry out definite movements, as animals do, and capture insects as a part of their food. Such are the sundew and the Venus's fly-trap. Then there are the plants that revel in the water of ponds, streams, and the sea; while the strange plants of the desert need every device for catching and holding the little water that comes to them. There are the many **wild** plants which man has not learned to use, and the **cultivated** plants, which he has nurtured for centuries, so that they may give him food, shelter, and clothing. Finally, besides the plant forms now upon the earth, there are the many that lived in past ages, and which we know only from their **fossils** (§ 281) in the rocks.

312. Parts of a Plant.— The parts, or **organs,** of our common plants are roots, stems, leaves, flowers, and seeds. The first three are **organs of nutrition.** All plants, like all animals, must have water and food. Food is needed for **energy** and for **growth and repair** (§ 298). There is, however, this important difference between plants and animals: green plants are able to take their food directly from the soil and the air, while animals must depend upon the materials plants have prepared. Out of the water, the minerals, and the decaying vegetable and animal material in the soil, and the gases of the air, plants build up the beautiful structures of their own bodies and the nutritious food which man and other animals eat.

But it is not enough for a plant to grow successfully; what is to continue the **kind** of plant when the individual plant dies? There are needed not only organs of nutrition, but **organs of reproduction,** by which some of the living material of one generation is set aside for the young plants that are to form the next generation. In this way the **species** of plant continues, although all the plants of each generation die. Flowers and seeds are the organs of reproduction. The seed of a plant, like the egg of an insect, a frog, or a bird, contains the young creature, called the **embryo** (ĕm′brĭ-ō), or **germ,** which, if allowed to develop in a normal way, will become a new being like its parent. The development of the plant embryo is called **germination.** When it is finished, the embryo has become a tiny, independent plant, or **seedling.**

313. How Seeds Germinate.— No description of the way in which seeds germinate can possibly take the place of actual experiment; therefore the student, or the class, ought to plan a small indoor garden, consisting of shallow dishes or boxes of good soil, in which seeds may be planted and observed, until they become seedlings. The **garden bean** is an excellent seed to study first.

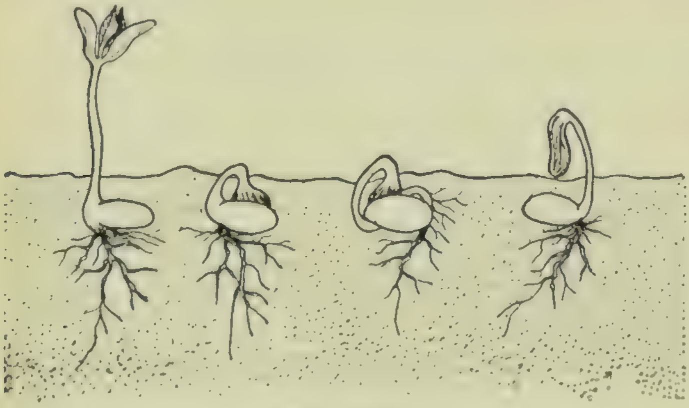


FIG. 275.
Germination of scarlet-runner beans.

Put a few, large, garden beans in lukewarm (not hot) water overnight, and examine them in the morning. They become **swollen,** because of the water that passes through the outer "skin," or **testa.** If you remove the skin of one of them, you will find the two "halves" of the bean; these are the **seed leaves,** or **cotyledons** (kŏt′ĭl-ē′dons). Between the cotyledons you will find the tiny **germ,** which can grow into the mature plant.

Plant 6 or 8 of the soaked beans in a row, say 2 inches apart, and "firm" the ground above them (see § 287). Plant also the same number of soaked squash seeds, scarlet-runner beans (Fig. 275), peas, lima beans, and corn grains. Add also a row of radish seeds, without soaking. Put your "garden" in a warm room, and where it will get good sunlight. Keep the soil moist, but not soggy.

In a few days you will see that the seeds have sprouted. The bean pushes up a crooked "stem," which lifts the dirt above it, straightens itself, and finally raises the two "halves" into the air. Between them you can see two tiny **leaves** (the **plumule**). At the same time the embryo stem, **or hypocotyl,** pushes down into the ground, and develops roots. The embryo is now a **seedling.** After a while the two cotyledons turn green, become thin, and finally fall off. They contained the stored nutriment upon which the embryo fed until it became established for itself; when this food is exhausted, they are discarded. The bean plant continues to grow by adding new leaves, two at a time, and by lengthening its stem through the **growing tip.**

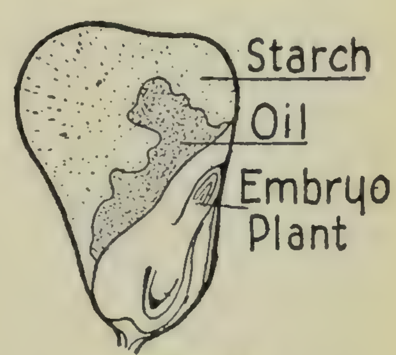
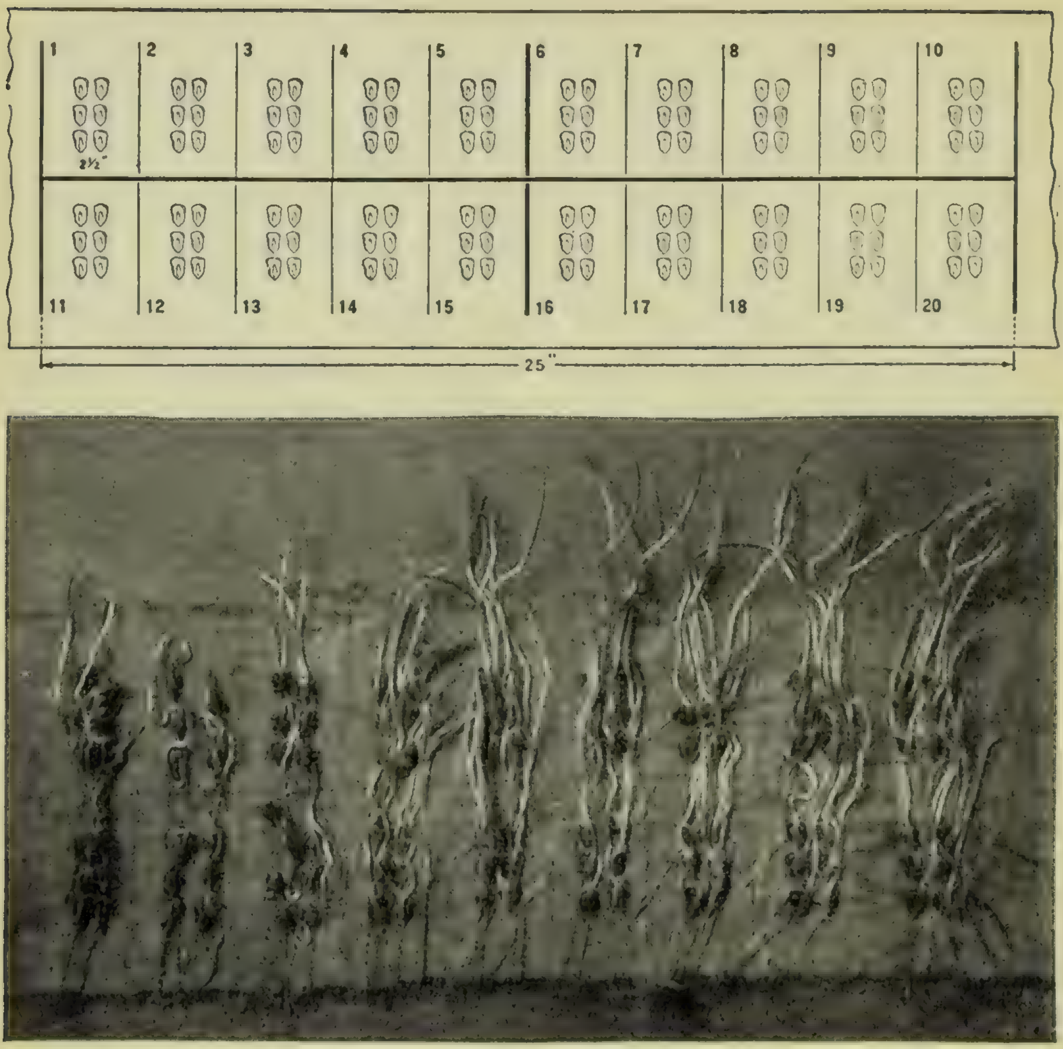


Fig. 276.
A grain of corn, cut through to show its structure.

Watch the germination of the other seeds, and note how they differ from the bean. In some seeds the food of the embryo is not stored in the cotyledons, but in the space surrounding the embryo; food thus stored is called the **endosperm.** In the pea the cotyledons remain inside the testa. In the castor bean they are lifted into the air, and become large and green; they do the work of true leaves.

In a large group of plants the seed has only **one cotyledon.** These plants are called **monocotyls,** while the others are called **dicotyls.** Corn is a monocotyl (Fig. 276). Its germ is at one side, just beneath the "skin." The embryo sends its plumule upward and its root end



Courtesy of the International Harvester Co.

FIG. 277.

This rag-doll seed tester is made out of muslin 9 in. wide x 5 ft. long, with 20 spaces 2½ x 4½ in., marked off with a soft pencil or a black crayon, and numbered. The spaces require 25 in. of the middle of the strip, leaving 17½ in. at each end, to be used for rolling up the seeds and for holding water. The lower figure shows a seed test 6 days old. Which seeds were the strongest and most likely to produce good corn plants?

downward, but the cotyledon and the stored food remain inside the "skin."

The modern farmer does not **guess** whether his seed is good or not; he **tests** it by letting samples of it germinate. Fig. 277 shows a **rag-doll** tester. The muslin strip is moistened before it is used. Six grains of corn from each of 20 ears are usually taken for a test. They are all laid with the tips (these are the **root** ends) pointing in the same direction. The **ears** of corn are numbered from the squares in which their samples are placed. One end of the muslin strip is rolled over the corn grains, and the whole strip is then rolled up tightly, and tied, so that the grains remain in place. The "doll" is then put, upside down, into a bucket of lukewarm water. The bucket should be wrapped in several thicknesses of newspaper or burlap, so as to insulate it (§ 53). After 10 hours the water is poured out, and the doll is set, right side up, under the empty, inverted bucket, and kept in a room at about 70° Fahr. If, after 3 or 4 days, the doll becomes dry, it may be moistened again with warm water. After 5 or 6 days it may be opened. The amount of growth made by each set of seeds tells the quality of the ears from which they were taken.

314. A Leaf.— Collect leaves of different kinds, and compare them (Fig. 278) as to their shape, thickness, color on both sides, and kind of veining. The broad part of a leaf is called the **blade.** Sometimes this is attached directly to the stem of the plant; sometimes there is a short leaf-stalk, or **petiole.** Some plants have tiny blades, or **stipules,** where the petiole joins the stem.

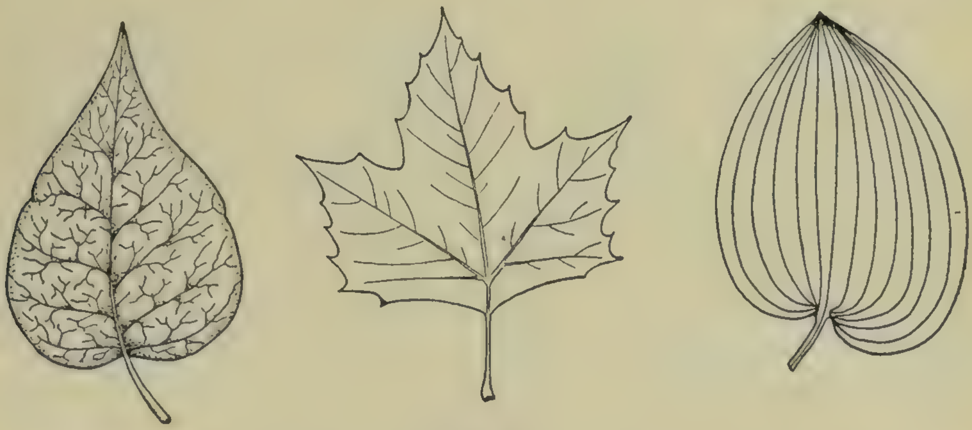


FIG. 278.
Leaves of the lilac, sycamore, and wild lily-of-the-valley.

The **blade** has a network of **veins.** A prominent, central one is called the **midrib,** or **midvein.** Veins are arranged in **three** general ways. In the lilac (left of Fig. 278) the leaf is **feather-veined,** like the barbs of a feather; sycamore and maple leaves are **palm-veined,** like a palm-leaf fan; while the lily-of-the-valley has **parallel-veined** leaves. What is the veining of elm, oak, corn, grass, geranium, cherry, and poplar leaves? Some leaves are broken up into **leaflets,** as in the clover and locust; they are called **compound** leaves. Some leaves are placed **alternately** on the stem; others are in pairs, **opposite** each other. Often many leaves are opposite one another, in a **whorl.**

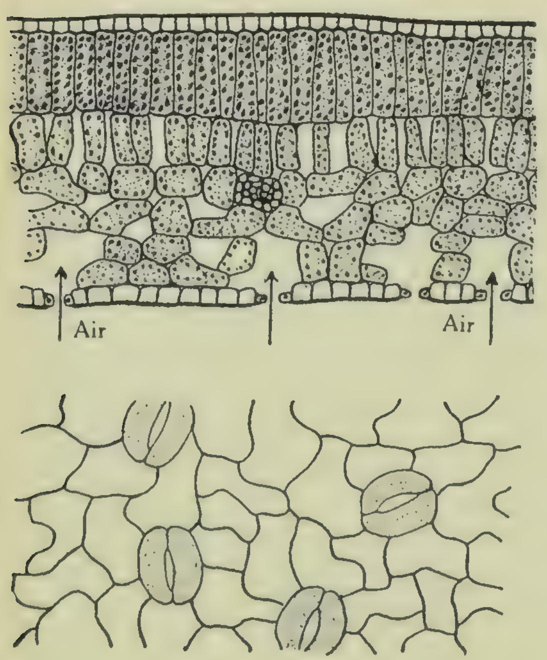


Fig. 279.
The upper figure shows the cross section of a leaf with its cells and stomata. The lower figure is a part of the epidermis. Both are greatly magnified.

A leaf is made up of **spongy tissue,** with an outer covering called the **epidermis** (ĕp′ĭ-dĕr′-mĭs). You can easily peel off the epidermis of, say, a geranium leaf. It is colorless. The epidermis, like other plant tissue, is made up of **cells** (Fig. 279). These are readily seen by the help of a microscope. Cells are the units of **living matter,** and contain living material, called **protoplasm** (prō′tō-plăsm; § 322). In the epidermis there are great numbers of slits called **stomata** (stō′mă-tă), which are the **breathing** places of the plant. Around each stoma there are **guard cells,** which control the size of the openings. Through the stomata the plant takes in air, and gives off the gases it does not need. The stomata also control the rate of evaporation of water from the leaf. In leaves that grow in a horizontal position, the stomata are on the under side. There are sometimes as many as 100,000 stomata to the square inch.

In the cells that make up the spongy tissue of the leaf there are **green** bodies containing **chlorophyll** (§ 65). The cells are packed together rather loosely, with **gas passages** between them. Thus the soft inner cells are protected by the epidermis; but at the same time they are in communication with the atmosphere outside.

315. What Leaves Do.— The leaf does several very important things for the plant. Its colorless, transparent epidermis acts like the **glass** of a cold frame (§ 214) in trapping sunlight. The stomata control water **evaporation** (§ 314); through them the leaf also serves as the "breathing apparatus" of the plant, taking in air and giving off carbon dioxide and waste gases. The fourth great duty of the leaf is to act as the **factory** of the plant. The leaf takes in carbon dioxide through its stomata, and gets water through the plant's roots and stem; and brings them together as the **raw materials** of the factory. Then the green bodies of the leaf cells use the energy of sunlight (§ 203) to cause the carbon dioxide and water to undergo a **chemical change,** and to form the compounds that the plant uses for its food and tissues. These compounds are sugar, starch, and cellulose, and similar bodies belonging to the class we call **carbohydrates** (§ 299). There is more oxygen in the water and carbon dioxide, taken together, than is needed to form the carbohydrates; the excess is poured into the air. Thus the green plant takes up carbon dioxide from the air and gives back oxygen (§§ 65 and 66). This work of the leaf is called **photosynthesis** (phō′tō-sĭn′-

thē-sĭs); the word means "put together by light." By this process plants make carbohydrates, not only for themselves, but for animals as well. Out of the carbohydrates and the materials brought from the soil the plant also makes **fats** and **proteins.** The leaf is thus the **world's greatest factory.** Other **green** parts, such as stems, can do the same work as leaves.

Factory	**Soap Factory** (§ 252)	**Plant**
Raw materials	Grease, lye	Water, carbon dioxide
Energy	Heat	Sunlight
Machinery	Soap kettles, steam coils	Green bodies containing chlorophyll
By-products	Glycerine	Oxygen
Product	Soap	Carbohydrate

We must remember that by the oxidation of their food and tissues plants exhale carbon dioxide and water, just as animals do. They must inhale oxygen. Photosynthesis, taking place in the light, reverses this change, and builds up the materials of food and tissues more rapidly than they are oxidized.

Leaves are sometimes very much changed for some special use. Thus, in the **sweet pea,** parts of the compound leaf (§ 314) are changed to **tendrils,** which wind about a twig or string, and hold up the slender stem of the plant. In the **ivy,** which depends upon a wall for support, the tendril is changed further to a **sucker,** or disk. Leaves are often changed to **thorns,** as in the barberry. In pitcher plants, sundews, and Venus's fly-traps some of the leaves are altered to form wonderful vessels, or traps, for the capture of insects.

316. Plant Stems.— The chief purpose of a plant stem is to connect the roots with the leaves, so that the water and minerals of the soil may reach the leaves. Along with this duty is that of holding the leaves and flowers up from the ground. Some stems are slender and climb by twining, as in the case of the morning glory; others, like the strawberry, run along the ground; others still remain under the ground, as in the case of the potato, iris, and bloodroot.

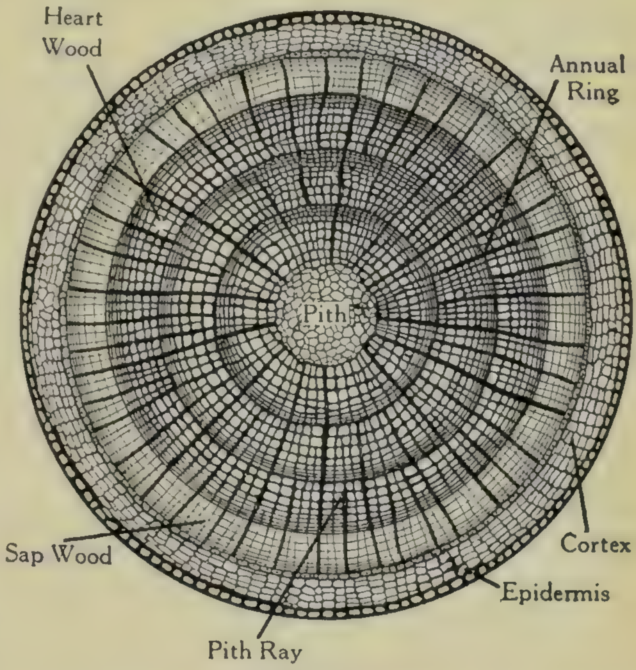


FIG. 280.
A cross section of a woody stem, showing the rings of growth and other markings.

Branches usually take such positions that the leaves get overhead light. Even when branches begin by growing upward, they are usually pulled down, by gravity, toward a horizontal position. The main trunk of a **tree** sometimes goes vertically upward, as in the poplar and fir, and sometimes divides again and again, as in the elm, oak, and hickory. One form of branching produces a **cone-shaped** outline, the other, a **spreading** one.

Leaves ordinarily appear only at certain places, called the **joints,** or **nodes,** of the stem. A bamboo fishing pole shows this jointed structure. The region of the stem just above the place where a leaf is attached is called the **axil** of the leaf. Buds and branches are usually formed only in the axils of leaves. Examine a plant stem, such as that of a geranium, catalpa, or sumach, for **nodes, axils,** and **leaf scars.**

If you cut across a growing woody stem, such as a lilac, maple, beech, oak, poplar, or box elder, you can make out **four distinct regions** (Fig. 280):

(1) An outer covering, the **epidermis.**

(2) A layer of soft tissue, generally **green** (the **cortex**).

(3) A layer of **wood.**

(4) A central part, the **pith. Pith rays** extend from the pith to the cortex, and divide the wood into **bundles.** When a tree decays at the center, what is being destroyed?

If you cut across the stem of Indian corn, you find that the woody bundles are not arranged in circles **around** the pith, but are scattered **through** the pith (Fig. 281). This is true of all **monocotyls** (§ 313). But woody **dicotyls** all have the ring-like structure. New wood is added to the tree, each growing season, just inside the cortex layer; consequently the number of rings gives us an idea of the age of the tree. Some of the **big trees** of the Pacific slope are 35 feet in diameter and over 300 feet high; they are estimated to be between 2,500 and 3,000 years old.

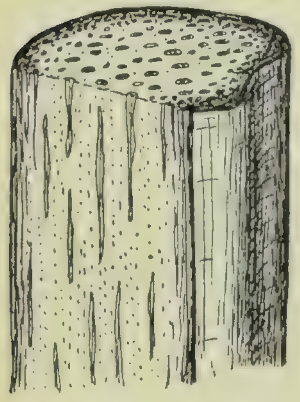


FIG. 281. Sections of the stem of Indian corn. The lengthwise section cuts through some of the woody bundles.

The **sap** is the liquid that brings food material to the plant cells and carries away waste material. In rising from the root it uses the cells of the woody tissue. As the tree grows old, the sap passes through only the outermost (new) wood cells, those near the cortex. The inner wood is called **heart-wood**; the outer is **sap-wood.** Heart-wood is preferable for lumber, since it does not warp or rot so readily as sap-wood.

The **sugar maple** has considerable sugar in its sap. In early spring men drill holes into the sap-wood, and insert spouts, down which the sap drips into buckets. They then boil the sap down, and obtain **maple syrup** and **maple sugar.**

The **bark** of a tree consists of the layers of old **epidermis.** As the tree grows in diameter, its bark is stretched until it cracks. In what **direction** does it crack? Why?

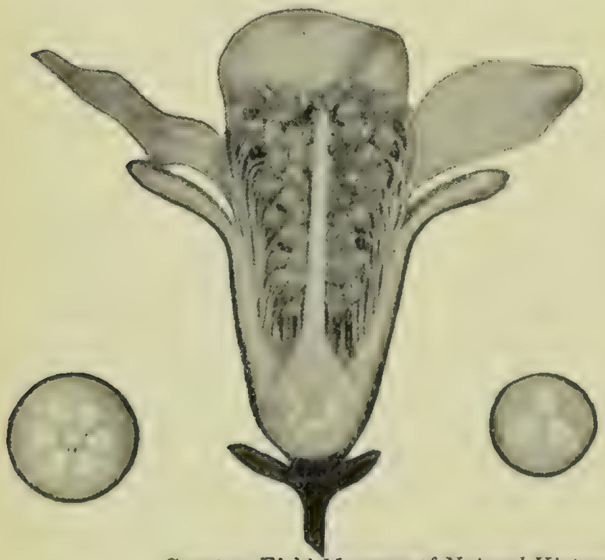
317. Buds.— Buds contain new, partly-formed leaves, stems, and flowers. In a **leaf bud** we find the stem very short, and its nodes close together. Therefore the leaves, which on the grown stem are far apart, overlap one another compactly in the bud. Most buds are dry and smooth on the outside, to keep out rain and snow. In **winter buds** the inside of the covering is often **woolly,** and protects the young leaves, stems, and flowers from sudden weather changes. The growing tip of each stem and branch has a **terminal bud.** Other buds usually grow in the axils of leaves (§ 316; **axillary buds**).

318. Roots and What They Do.— We have learned that leaves are the factory of the plant (§ 315). The leaves take in carbon dioxide, but the water, nitrogen compounds, and minerals come to the plant through its **roots.** The other plant organs seek the light, the roots avoid it. They go through the soil in all directions, gaining a firm **foothold** for the plant, and taking in food and water from as much soil as possible. It is for this reason that the farmer tries to give his soil a good structure (§ 286).

A root does not push itself, as a whole, through the soil. Each **growing tip** is protected by a **cap** consisting of layers of cells. The tip is pushed forward by the force of new cells growing behind it, and thus lays a "pipe line," a section at a time, from the food storehouse in the soil to the stem and leaves above ground. The actual passage of soil water and its dissolved materials takes place not through the wall of the larger, older part of the root, but through the delicate walls of a multitude of **root hairs** that cover the growing rootlets. The root hairs adhere closely to the particles of the soil. The soil water passes through their walls much as water goes through the "skins" of dried prunes and beans when we "plump" them by soaking.

If a root goes down in one main portion, as in the dandelion and radish, we call it a **tap-root.** If the root has many fine branches, we say it is **fibrous.**

319. The Work of Flowers.— Flowers are the organs by which the higher plants pass on the spark of life from one generation to the next. While a flower is still a bud, it usually has a green, leaf-like covering. When the bud opens, its covering appears as the first, outer set of parts of the flower. We call it the **calyx,** and its parts we call **sepals.**



Courtesy Field Museum of Natural History.

FIG. 282.
Lengthwise section of a pomegranate flower.

The attractively colored part of the flower is the **corolla**; its separate parts are **petals.** The calyx is sometimes highly colored, too, but usually it is green, like true leaves. Often the calyx, or the corolla, is in one piece, with the sepals (or petals) joined. This is true in the morning glory, the bluebell, and the petunia.

A **complete** flower has **four sets of parts** (Fig. 282). The calyx and the corolla are the most leaf-like, and enclose the **stamens** and **pistil,** which are the real organs of reproduction. The stamens produce a powdery substance, generally yellow, which is called **pollen.** A **stamen** usually has two parts: the stalk, or **filament,** and the real pollen case, or **anther.**

Inside the circle of stamens is the **pistil**, the structure in which the seeds of the plant are produced. In its simple form the pistil consists of a bulb-like seed case, or **ovary**, above it a stem, or **style**, and, at the tip of the style, a sticky, outspread surface called the **stigma**. A simple pistil is also called a **carpel**. Often the **pistil** is **compound**, and consists of several carpels more or less joined together. In the ovary the **ovules** are produced; when mature, these are **seeds.**

The top of the flower stalk, on which the parts of the flower are arranged, is called the **receptacle.**

The number of flower parts in a set is usually 3, 4, or 5, or some multiple of them. Thus in the buttercup there are 5 sepals, 5 petals, and often 30 or more stamens. How many of each kind of flower parts are there in apple and cherry blossoms, in the tulip, and in the trillium?

320. How Seeds are Formed.— Before the ovule in the ovary can become a seed, it must be **fertilized** by the pollen. The flower exists for this purpose. When the flower is fully developed (mature), the pollen case breaks open, and the pollen grains are carried by the wind, or insects, to the sticky surface of the stigma. Here the pollen grain grows a long tube through which the fertilizing **pollen cell** can pass. The tube grows through the style into the ovary and then into the ovule. When the pollen tube reaches the **ovum,** or egg cell, inside the ovule, the **pollen cell and egg cell unite.** As a result the egg cell develops very rapidly, and becomes the **embryo.** The ovule forms a hard coat (the testa) about the embryo, and stuffs the cotyledons and any vacant space with food (endosperm). The completely equipped ovule is now a **seed.**

Pollination is the transfer of pollen from the **anther** of a stamen to the **stigma** of a pistil. The pollen may come from the same flower as the pistil, or from another flower of the same kind. The air is often loaded with pollen grains. Many plants do not depend on chance for their fertilization, but have devices to attract insects or birds. This is the reason for bright colors and sweet odors, which tell the visitor where food is to be found. For some creatures, such as butterflies, the flower prepares a sweet liquid, called **nectar.** Bees feed upon the pollen itself. The nectar is likely to be stored **beyond** the stamen or pistil, so that the visiting insect must brush against these organs. The insect thus becomes covered with the pollen grains of one flower, and carries them to the stigma of the next. Some flowers have a perfume only at night, when the moths that bring about their fertilization are seeking food.

321. How Seeds are Scattered.— It will not do for all the seeds produced by a given plant to germinate and attempt to grow in the spot where the parent plant grew; hence most plants have worked out some way by which their seeds can be scattered (Fig. 283). Thus the violet and the wild bean produce a great many seeds in a pod. When the seeds are fully ripe, the pod bursts with considerable force, throwing the seeds some distance away. Maple seeds have "wings," and dandelion and thistle seeds have downy structures or little parachutes, so that they may fly away on the wind. Seeds are carried away by streams and by the ocean itself. **Burdocks** and stick-tights produce "stickers" by which their seeds are carried away by animals and

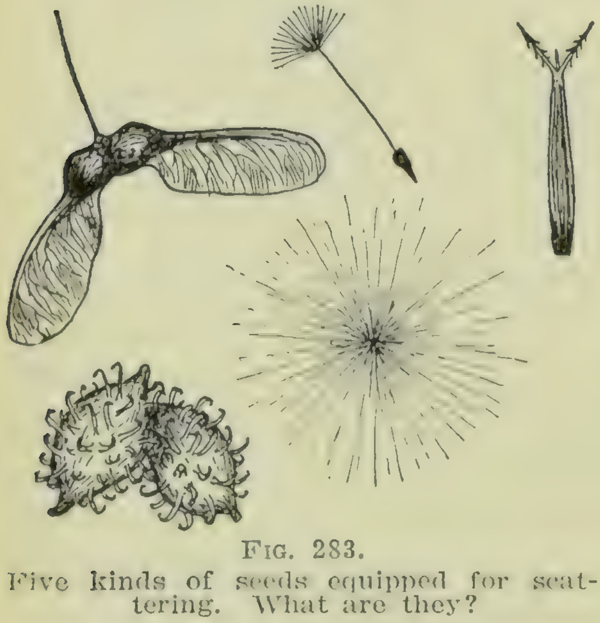


FIG. 283.
Five kinds of seeds equipped for scattering. What are they?

man. **Fruits** are devices by which seeds are scattered. The fruit is carried away, and its fleshy part is eaten, while the seed is left in a new place.

322. Plants Without Flowers.— The plants we have been studying are those that produce flowers. They are the highest in development. But there are multitudes of kinds of plants that produce no flowers, and yet have structures that act like seeds in carrying on the life of the species. This is true of **mosses** and **ferns,** as well as of **fungi** (fŭn′jī) like toadstools, mushrooms, and puffballs. **Molds** are plants of a low order, which grow upon food, leather, and other organic material. **Algae** (ăl′jē) form a large class of plants (chiefly water plants), varying in color from green to red, brown, and the like, and in size from a single cell to masses many feet long. Pond scums and sea weeds belong to this class.

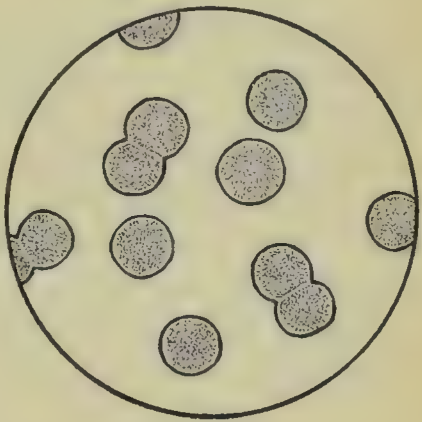


FIG. 284.
Cells of pleurococcus, magnified.

One of the very simplest plants is called **pleurococcus** (Fig. 284). It is the **green stain** found on the north side of trees and fences. When we examine it with the microscope, we find that each plant consists of **one cell** (§ 314). Grains of chlorophyll in the protoplasm give the plant its green color. In order to produce new cells, a cell **divides.** Its protoplasm separates into two portions, a cell wall forms between them, and there are now two cells instead of one. This is reproduction by **cell-division** (§ 353).

323. Preservation of Wild Flowers.— How many of your class have ever found the wild columbine, lady's-slipper, bloodroot, hyacinth, pitcher-plant, or wake-robin, growing in its natural home? These exquisite plants once grew abundantly in many parts of the country where they are rarely, if ever, seen now. What has become of them?

Of course we know that, as the country has become more and more thickly populated, the prairies and meadows have been cultivated, the swamps drained, and the forests cut down. As a result multitudes of wild flowers have lost their homes. But this is not all. Much unnecessary loss is caused by thoughtless people, for whom a wild flower exists only to be plucked, often roots and all.

Is it not worth while for us to think of our wild plants, as of our birds (§ 343), as a wonderful **heritage** to be cherished and saved from destruction? Can we not get far more pleasure from wild plants by letting them **grow,** so that we can go back to see them, year after year, than from tearing them up to wither and die? Few wild flowers last long, when carried from the country to the city. Even country children ought to pick only a few flowers of any one kind, so that there may be many left to grow on, for the enjoyment of the children of future generations.

324. Exercises.— 1. Why do not mushrooms have chlorophyll?

2. Why are potato sprouts white when formed in a cellar?

3. Many tropical plants have leaves with gutter-like tips; why?

4. What preparation do trees and shrubs make for winter?

5. Describe the roots of the dandelion, sweet clover, lettuce, corn, tulip, cabbage, bean, and sweet potato.

6. Why do forest flowers, such as the hepatica, spring beauty, and bloodroot, bloom in the early spring? What plants produce flowers before they produce leaves?

7. Name some plants of the desert portions of the United States. What peculiarity do they have?

8. Are young plants ever started without seeds? What is meant by the "slipping" of such plants as geraniums? Are strawberry plants grown from seeds?

9. How does the embryo bean differ from the seedling?

10. How do the tumbleweed and thistle scatter their seeds?

11. Is a dandelion one flower, or many? A red clover?

325. Plants of Use to Man.— The plants used by man for himself and his domestic animals are very numerous. The most important are the **grasses,** some of which were developed by man long before the dawn of history, and became our **grains. Indian corn** is a native of America, and was developed by its primitive inhabitants. The flax plant has given man **linen** since the distant past. **Cotton** was known to the ancients, but its use on a large scale had to wait for the invention of the **cotton-gin,** which made cotton-raising profitable in America. The **potato** is native to South America, but it was developed into edible form in Europe. Out of trees we get lumber and the **pulp** for paper. Because of rapid transportation we no longer depend upon our own neighborhood for our food, but the fruits of the tropics are brought to our doors. Fresh vegetables, which our fathers had during only a short season, come to us, all winter, from far-away gardens of the South.

326. Improvement of Plants.— Science and its methods have not only increased our home comforts and conveniences, and improved our means of communication and transportation, but they have improved the quality and increased the production of our food plants. Not only this, but they have produced new varieties of plants and plant products. Thus James L. Reid, of Illinois, originated Reid's Yellow Dent corn, which is probably the most generally grown corn in the world; and Luther Burbank developed the Burbank potato, the blue poppy, the Shasta daisy, the plumcot, and a spineless cactus; while Ephraim Bull, of Concord, Massachusetts, by a process of careful selection of the offspring of some wild grapes, produced the Concord grape.

If you had some corn plants (Fig. 285) in which the ears grew low on the stalk, how could you produce a corn plant in which the ears grow high on the stalk? A remarkable fact about plant development (the same is true of animals) is that offspring are very rarely exactly like their parents, or like one another. This is called **variation.** If you plant all the seeds produced by the low-eared corn, no two of the plants produced will be exactly alike. Some will have the ears a little higher, others a little lower. If you select, for the seed of the following season, an ear from the plant that produced the highest ears, you will again get low-eared and high-eared plants, but some plants will produce ears higher up than any of the season before. After a few years of this **artificial selection,** you will obtain the high-eared variety.

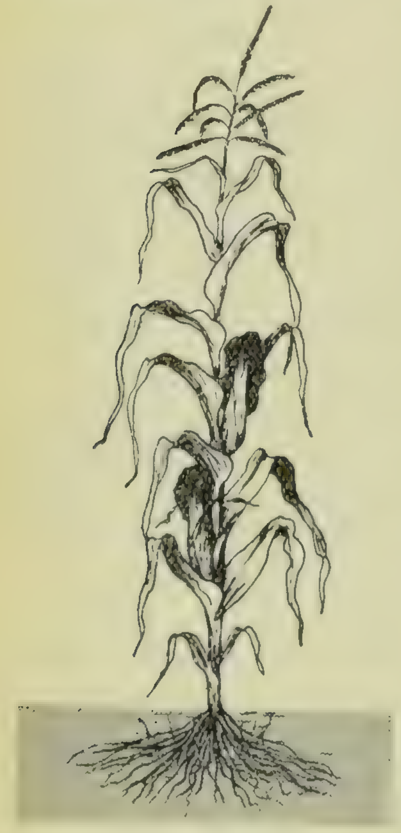


FIG. 285.
A plant of Indian corn. Note the tassels at the top, the ears, with their silk, in the leaf axils, and the long, parallel-veined leaves.

Another way of changing some particular quality of a plant is by **cross-fertilization,** that is, by allowing the pollen from a certain type of plant to fertilize the ovule of another type. Thus Burbank produced the Shasta daisy by a combination of the characters of three varieties of daisies. From our own wild daisy and one obtained from Europe he obtained a few plants that bore unusually large flowers. These large daisies were not, however, white enough. So he cross-fertilized them again, and introduced the quality of whiteness from a Japanese daisy, which though small, was pure white. The result was the Shasta daisy.

327. Our Grains.— From what part of a plant does our food come? Of some plants we eat the **flower** or some of its parts, developed into seeds or fruit; of other plants we use the **leaves**; of others again, the **stem**; and of still others, the **root.** The seeds that we eat belong chiefly to two great plant groups: (1) those of the **grasses,** which give us our grains; and (2) those of the plants, like beans and peas, having special pods, or **legumes** (lĕg′yūms). See §§ 32 and 328.

The **grass family** has thousands of species. These differ in many ways, but they are alike in having very simple flowers and in producing a seed-like fruit. The flowers have only stamens and pistils, no sepals or petals. The grasses have peculiar scales, or **bracts,** to protect their seeds. It is these bracts that fly off when grain is threshed; we call them **chaff.** **Corn** differs from the other common "grasses" in that its stamens and pistils grow some distance apart. The **stamens** are the **tassels,** and grow in clusters at the tips of the stalks; the **pistils** form the **ears,** and grow in the axils of the leaves, on the sides of the stalks. What is the "silk" of the corn ear? The grasses are **monocotyls** (§ 313).

The **sugar cane** and **sorghum** plants are grasses used for their sap; the **bamboo** is a grass that grows to the size of a tree. Grasses used as **fodder** for cattle are timothy, blue grass, and redtop.

Wheat is of two kinds, **spring** and **winter,** according to the time of planting. Winter wheat is planted in the fall. It germinates and makes a little growth before the ground freezes and snow comes. The green shoots may freeze, but the plant as a whole does not. Because it makes so early a start, winter wheat is ready for harvesting early in summer, long before the spring wheat.

Corn has many varieties. We think at once of **sweet corn, popcorn,** and **field corn.** The two principal kinds of field corn are **flint** and **dent** corn. Flint corn gets its name from the fact that it is **hard** and **translucent,** like flint; it is generally best for a region with a short summer, as it ripens very quickly. **Dent** corn has a soft, large grain with a dent at the top. It often grows to a great height, but it sometimes requires 5 or 6 months to ripen properly. Which of the two does pop-corn resemble more?

Rice belongs to the grass family, but it begins its life as a water plant. It is planted in flooded land, and needs a soil that remains very moist.

Why is it that with so many grains, such as barley, rye, oats, rice, and corn, to choose from, people prefer **wheat** for their yeast bread? The reason lies in the composition of wheat. Wheat contains more sticky material (**gluten**) than other grains. When yeast ferments bread dough, producing bubbles of carbon dioxide (§ 64), the gluten holds the gas bubbles in the dough, so that the baked bread is light. **Rye** is next to wheat in this respect. Gluten is the protein of wheat.

Wheat flour is the powdered wheat grain. If the seed coat is left in, we have **graham** flour; if the seed coat, and nothing else, is removed, the product is **whole wheat** flour. The seed coat forms **bran.** White flour is **bolted,** or sifted, through fine cloth; thus bits of bran, and the darker, harder, outside parts of the grain are removed. Bolted flour has lost some of the nutritious material of the grain (§ 303). **Hard** wheats are those with much gluten. **Macaroni** wheats have so much sticky material that they are not good for making bread. Why?

328. Leguminous Plants.— Leguminous plants, or **legumes,** as they are usually called, include clover, alfalfa (**lucerne**), peas, beans, lentils, vetches, wisterias, bluebonnets, the locust and redbud trees, and many others. All have their flowers in clusters. The **sweet pea** illustrates the flowers of the legumes. One of the petals, much larger than the others, stands upright, like a **banner**; two of the petals resemble **wings**; the remaining two look like the **keel** of a boat, and form a box for the stamens and pistil. The attractive odor and color of the blossom suggest that insects or other creatures are needed to help fertilization. The **keel** is a device by which the insect that visits it is made to carry pollen from one flower to another.

Clover blossoms have many separate flowers in a close **head.** What do they produce to attract insects? The **peanut,** or **goober,** is a legume. Between the cotyledons is the embryo, as in the bean. Peanuts are **dug** from the ground. The flower is produced above ground, but when the pods develop, the plant forces them into the ground to ripen.

We have already learned (§ 32) of the interesting partnership between the legumes and nitrogen-gathering bacteria, and of the way in which this partnership brings nitrogen compounds into the soil.

329. Leaves, Stems, and Roots as Food.— Our common garden vegetables include the leaves and stems of certain plants, as well as seeds. In the asparagus, celery, and rhubarb the **stalk** is the edible part; in lettuce, spinach, and cabbage, the **leaves.** Tomatoes and cucumbers are **fruits** (§ 330). We eat the **starchy** vegetables chiefly because they are fuel foods (§ 299). We eat **juicy,** or succulent, vegetables for their **flavor,** and to add **bulk** to our food, as well as for their **minerals** and **vitamins** (§§ 301 and 303).

How the parts of a plant may be altered by artificial selection (§ 326) is well illustrated by the **cabbage** family. The cultivated cabbages include kohlrabi, kale, head cabbage, Brussels sprouts, and cauliflower. The parent plant is the wild cabbage of the British Isles and western Europe. This has a branching stem and two kinds of leaves, the lower ones broad and the upper ones small. In the kohlrabi the **stem** just above the ground has become enlarged and turnip-shaped; in kales there are large spreading **leaves**; in cabbages the broad leaves form a **head**; in Brussels sprouts **axillary buds** (§ 317) on the stem just above the ground, develop into small heads; in the cauliflower we eat the altered **flower** itself.

While the sweet potato is a root, the common potato is an **underground stem,** or **tuber.** The "eyes" are **leafy scales,** with very small leaf-buds in the axils. The development of the potato since the discovery of America has added enormously to the world's food supply.

A plant which both grows from a seed and produces seed, in one growing season, is an **annual.** Name some annuals. Many plants (**biennials**) need two seasons to produce seed. During the first season they store away nutriment for the growth and seed production of the second season. Name some biennials. Roots, stems, and leaves are used for underground storage. The **tuber** of the potato, as we have seen, is a stem. The rootstocks of ferns, wild ginger, iris, and bloodroot are underground stems. The **bulbs** of the onion and lily are underground **leaves** stuffed with nutriment. The sweet potato is a **branching** root; the turnip, beet, parsnip, rutabaga, and carrot are thickened **tap-roots** (§ 318).

Plants that last from year to year are **perennials.**

330. Our Fruits.— A fruit is really a ripened **ovary,** or egg case, and its contents. In popular language, however, we think very little of the seed, but only of the pulpy tissue, which we eat. Such "fleshy" fruits include berries, cherries, plums, apples, melons, citrous fruits, bananas, and many others.

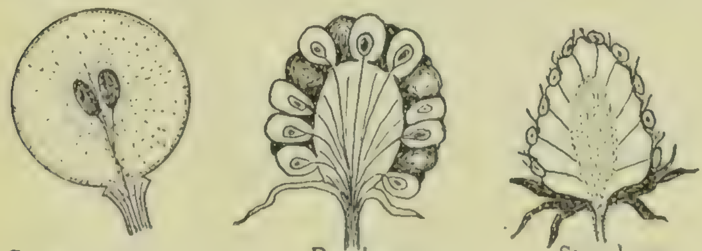

Grape Raspberry Strawberry

FIG. 286.
Lengthwise sections of three "berries."

A real **berry** (Fig. 286) is an ovary with its seeds and fleshy material and a thin, outer "skin." Grapes, gooseberries, and blueberries are real berries. A **raspberry** is a **cluster** of berries, which readily comes off from the **receptacle,** on which it grows (§ 319). In the **strawberry** we find the gritty seeds on the outside, set into the pulpy **receptacle** that we enjoy eating. In a **blackberry** we eat both the cluster of berries and the receptacle.

Citrous fruits, such as oranges, lemons, and grapefruit, have a tough, leathery "hide" in place of the thin skin of the berry. In pumpkins and melons the ovary walls become hard **rinds.** In stony fruits, such as peaches and cherries, the ovary wall develops in **two layers**: (1) a hard layer surrounding the seed; (2) a pulpy layer with a thin skin.

Bananas are berries, but their seeds are only remnants, and never develop into new plants.

Apples, pears, and **quinces** are much alike. Their flowers are all built upon the plan of **5,** and a cross section of the fruit shows 5 seed cases in the core. The top of the fruit shows the remnants of the calyx, stamens, and styles, and a lengthwise section through the core shows how these are related to the ovary. The fleshy part of the apple is chiefly made up of the developed **receptacle.**

331. Weeds.— A weed is a plant **out of place,** as grass in a flower garden, or daisies in a hayfield, or dandelions on a lawn. Men have had to fight weeds since they began to cultivate soil, and only those weeds that can take advantage of every opportunity have been able to survive. As a result, weeds are very **hardy.** Having their own life to live, they take possession of our fields and orchards, choke up canals and irrigation ditches, cover railroad tracks, cut off light from cultivated plants, and attach themselves, as **parasites,** to other plants. **Cultivation** of plant crops and trees is partly for the destruction of weeds (§§ 289 and 292).

Which of the following weeds do you know: sorrel, plantain, milkweed, dock, quack grass, shepherd's-purse, pigweed, wild mustard, mullein, Canada thistle, lamb's quarters, smartweed, tumbleweed, and fireweed?

332. Trees and Their Products.— The pioneers of this country found a wonderful growth of trees awaiting them, but so great has been the demand for lumber, and so reckless the cutting and burning of our forests, that much of our timber has already disappeared, and good wood is becoming scarce and expensive.

Wood is valuable for houses, furniture, boxes, tools, and the like because it can be split, sawed, and worked so easily, and its pieces can be so readily fastened together by nails, screws, and glue. The wood of some trees splits very easily "with the grain," because the **woody bundles** of these trees (§ 316) are in straight lines in the rings of growth. **Quarter-sawed** oak is produced by sawing the oak log always from the circumference toward the center. The cut is thus made lengthwise through the **pith rays**; as a result the wood has beautiful, flaky markings. **Knots** are old branches.

Our building woods are **hard** or **soft.** White and Norway pines, hemlocks, and firs are **softwoods**; oak, beech, birch, maple, cherry, walnut, and mahogany are **hardwoods.** We generally use a hardwood for the inside, and a softwood for the outside of a house. Why? Southern pine (hard pine) is often used for inside woodwork.

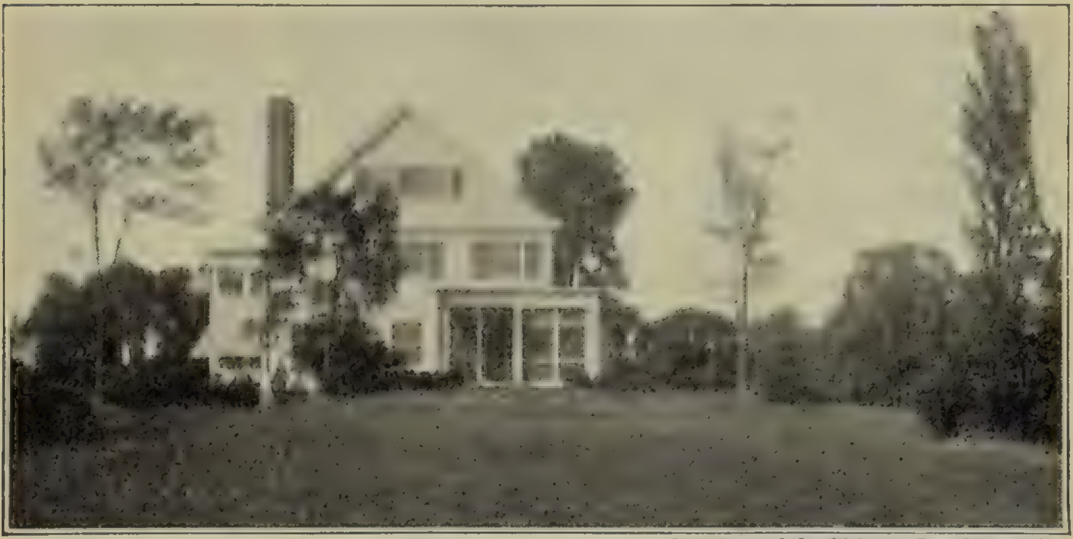
The **sap** of the rubber tree of South America and Africa gives us **rubber**; the resinous liquids of the Southern pine give us **turpentine** (§ 31); by heating the leaves and wood of the camphor tree we get **camphor**; from the bark of the cork tree we get **corks**; and from oak and hemlock we obtain **tanbark** for tanning leather.

The **paper** used for newspapers, magazines, and ordinary books is a forest product, for it is made from **wood pulp.** The wood (spruce, or other softwood) is heated, as chips, with alkali or "bisulphite"; this treatment gives chiefly **cellulose.** Pressed paper pulp is like blotting paper or filter paper. **Filling** with a substance like clay is needed to make it less porous. For a writing paper, on which ink will not "run," the pulp must be filled, and then **sized** with a substance like gelatine or rosin. Finally the paper is **polished** between rollers.

333. Beauty in Planting.— Plants are valued by man not only because of their usefulness, but also because of their beauty. Trees are planted along streets and in our yards not only as a protection against the summer sun, but also because their beauty pleases our eyes. In great cities, in which an acre of land may be almost priceless, large tracts are set aside as parks, and planted with trees, shrubs, grass, and flowers. Park trees are not crowded together like the trees of a natural forest, nor are round flower-beds dotted about in wide stretches of lawn. All good planting is done according to certain **rules**, so that the most beautiful result may be obtained. These rules apply not only to the planting of parks, but also to our yards (Fig. 287).

1. In a park or large yard trees should be planted in **groups**, rather than spaced at equal intervals.

2. Groups of shrubs should be planted **near a house**; they soften the hard line where the house meets the ground, and make the house look as though it belongs where we find it. Other groups of shrubs are often placed along the boundary of a yard or following a path.



Courtesy of the Chicago Landscape Co.

FIG. 287.

A well-arranged lawn. Does it follow the seven rules of planting?

3. Small plants or flowers should be placed outside of, or in front of, tall plants or shrubs, in attractive masses or in a curving border. The flowers then look their prettiest against the background of green vegetation.

4. When we put flowering plants near one another, we should take care that the flowers which bloom at the same time are **harmonious,** and look well together.

5. We should study our planting, so that we may have flowers

blooming all through the season. Then, when the early spring flowers fade, the late spring flowers will appear, and those of summer and autumn take their turn.

6. The lawn should never be **overcrowded** with shrubs and flowers. Soft expanses of green sod add beauty to the garden.

7. Trees and shrubbery should not be so **dense** that the view from or to the house is completely shut off.

334. Summary.— **Plants** are active, living creatures.

The **organs** of a plant are root, stem, leaves, flowers, and seeds. Their functions are **nutrition** and **reproduction.**

Germination is the change from seed to seedling.

The **seed** of a bean consists of **testa** and **embryo.**

The **embryo** consists of **cotyledons, hypocotyl,** and **plumule.**

Leaves consist of **blade, petiole,** and sometimes **stipules.**

A **leaf** has an **epidermis,** with **stomata,** and **leaf-tissue.** Its **cells** contain **protoplasm** and green bodies with **chlorophyll.**

The **leaf** is the **factory** of the plant.

Stems have **nodes** and **buds.** Those of dicotyls have **annual rings.**

Sap carries nutriment; it rises through the **newer wood.**

Buds are stems, leaves, and flowers in undeveloped form.

Roots are the plant's feeding organs for soil nutriment.

Flowers consist of sepals, petals, stamens, and carpels. **Simple** pistils have one carpel; **compound,** two or more.

A **stamen** consists of **filament** and **anther.**

A **carpel** (simple pistil) has **ovary, style,** and **stigma.**

Fertilization is the union of a pollen cell with the egg cell of an ovule. The fertilized ovule becomes a **seed.**

The **preservation** of wild flowers is worth while.

Plants may be **improved** by selection and cross-fertilization.

Grains are **seeds** of the **grass** and **legume** families.

Wheat is preferred for flour because of its **gluten.**

Vegetables may be roots, stems, leaves, flowers, or seeds.

Plants may be **annuals, biennials,** or **perennials.**

A **fruit** is the **ripened ovary** and adjacent parts.

Weeds are plants out of place.

Tree products are wood, maple sugar, rubber, turpentine, camphor, cork, tanbark, and paper.

Good planting is done according to certain rules.

335. Exercises.— 1. How would you develop a seedless orange?

2. Which of our plant foods were rare 100 years ago?

3. Name the commercial products made from corn.

4. What is the reason for "curing" hay and clover?

5. Why does a working horse need oats as well as hay?

6. Name some plants that scratch you when you touch them. Some that poison you. Some with a disagreeable odor.

7. Why should we leave soil upon roots in transplanting?

8. Why do perennials lose their leaves in autumn?

336. Projects.— 1. Make a collection of a leaf, twig, and bud from each kind of tree in your neighborhood.

2. Make a collection of 20 wayside plants (weeds) in your neighborhood, and get their names.

3. Bring 5 different kinds of flowers to class, and demonstrate the organs of each.

4. Show the class a collection of roots, including vegetable roots, and classify them as in § 318.

5. Show the class a lengthwise and a cross section of a cabbage, a cauliflower, a kohlrabi, and a Brussels sprout.

6. Show the class lengthwise and cross sections of an apple.

7. Prepare an exhibit of ripened ears of corn, including pop-corn, and show the differences in grains and cobs.

8. Carry out the 6-day rag-doll test with corn, beans, peas, and other seeds.

9. Open the pits of a number of stony fruits and describe the structure of the embryos to the class.

10. Describe the structure and qualities of several kinds of potatoes.

11. Determine by experiment the effect of covering a growing geranium leaf with paper for several days; also of bringing white potato sprouts into sunlight.

12. Collect samples of several hardwoods, including quarter-sawed and common oak, and softwoods, and show their qualities to the class.

13. Write a paper on the useful tree barks.

14. Make a tree census of your neighborhood, the number and kinds of the trees, their age, value, and improvement.

15. Prepare a paper on Arbor Day and its value.

16. Prepare a paper on the invention of the machine reaper.

17. Prepare a debate: Resolved, that corn is of more value to the world than wheat.

18. Make a map of some yard in your neighborhood, marking the position of the house, walks, and drives, and of each tree and shrub. Suggest possible improvements.

19. Make a diagram of a city back-yard and show how to plant it for use and beauty.

20. Plan, plant, and carry on a vegetable and flower garden in your home or school yard.

337. References.— BAKER: *Yard and Garden.* COULTER, BARNES, AND COWLES: *A Textbook of Botany.* DANA: *How to Know the Wild Flowers.* DOWNING: *Our Living World.* Farmers' Bulletins, U. S. Department of Agriculture. MACBRIDE: *Common Wild Flowers.* INTERNATIONAL HARVESTER COMPANY: *Grow a Garden*, and other circulars. ROBBINS: *Botany of Crop Plants.* ROGERS: *Trees Every Child Should Know.* SMITH AND JEWETT: *Introduction to the Study of Science.*

CHAPTER XIX

ANIMALS OF ECONOMIC IMPORTANCE

338. Animals as Beasts of Burden.— When did man begin to **domesticate** animals, that is, to make them a part of his **household?** That day is far back in the past. When the curtain of history rises, we find the more advanced peoples of Europe, Asia, and northern Africa living in settled communities, cultivating the soil, and having such animals as dogs, horses, cows, sheep, goats, and chickens.

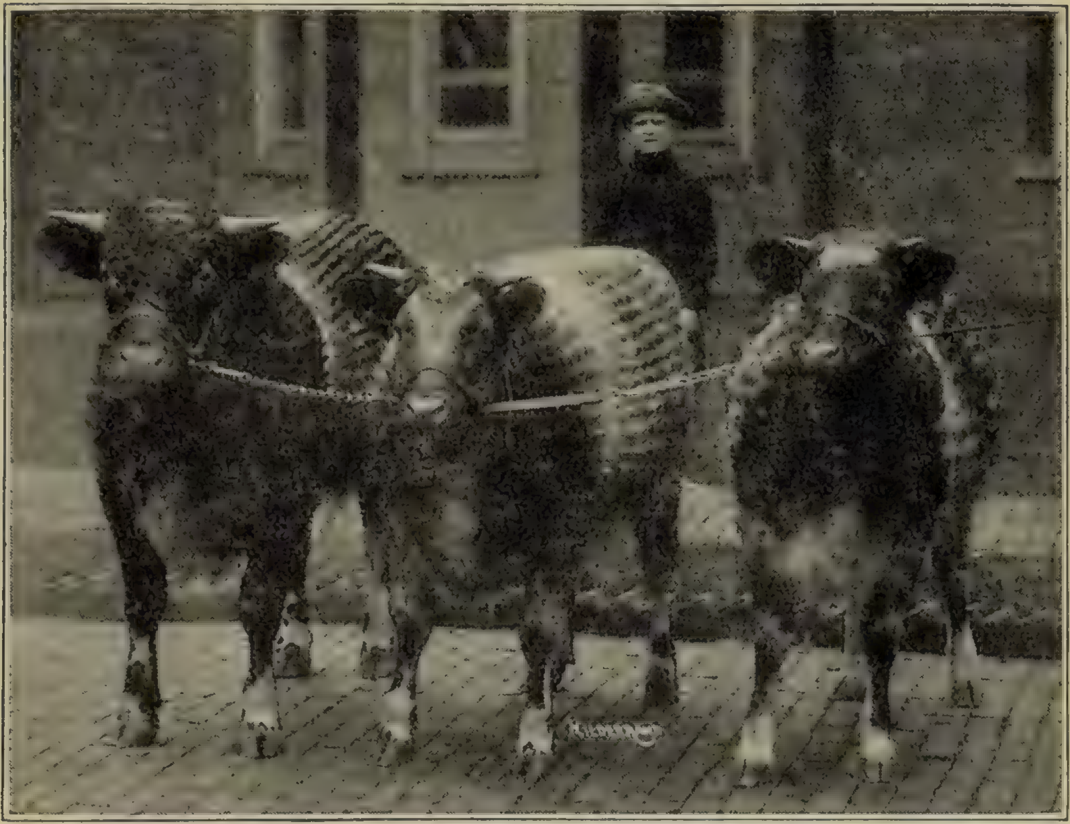
Early man seems to have lived upon the fruit, seeds, and roots of wild plants, and upon insects, worms, and other small animals. When he had invented **weapons,** he was able to kill large, wild animals, and to live upon meat. It was a great day, when, with traps, snares, and pitfalls, men began to capture animals **alive,** and to domesticate them. By making a home for his animals, man more and more made a **home** for himself. At first it was a **movable** home, and he wandered about with his flocks and herds, seeking water and pasture, just as the nomadic tribes of Asia and northern Africa do today. Gradually, however, men learned to domesticate plants, too, as food for themselves and their animals. Instead of being a wanderer, man became a **farmer,** and built up settled communities and **nations.**

When we speak of beasts of burden, we think naturally of the horse; but the **ox** probably pulled carts and plows long before the horse. The ox is still used in some parts of this country. The **mule** is also important as a beast of burden. In the Far East the **water buffalo** is used in this way (Fig. 2, *a*). In the deserts of Asia and Africa men use the **camel,** in northern Europe and Asia, the **reindeer.** The reindeer has been introduced into Alaska. It finds much of its own food, even in winter, by pushing away the snow and getting at the green moss underneath. **Dogs** are important beasts of burden, not only in the land of the Eskimo, but in the countries of western Europe.

The **fossil** remains of horses show that the horse probably developed **first** in America. The earliest fossils are those of an animal of the size of a dog or fox; later fossils show a larger and larger animal. The fossils of the first horse show an animal with five toes to each foot. The succession of fossils shows that as time went on the first and fifth toes became mere splints. This gave a three-toed horse. Then the second and fourth toes became splints, too, while the splints of the first and fifth toes disappeared entirely. The modern horse walks upon the third (middle) toe, and has still the useless splints that represent the second and fourth toes of it's ancestors.

For some reason the race of horses developed to its fullness only in the eastern hemisphere, and died out in the western. One of the probable reasons why primitive man developed so much more slowly in America than in Europe and Asia was that in America there were no beasts of burden like the ox and the horse. Before the white man brought them, the Indian had no horses. Indian ponies are the descendants of the horses brought over by the early explorers and settlers. The only beast of burden to help the American Indian with his work was the **llama,** or South American camel, used by the inhabitants of Peru; but its use never became common over the continent.

339. Animals as Food.— For food man has used not only his beasts of burden, but a great many animals besides. Cattle (Fig. 288), sheep, and swine are the most common four-footed animals used as food. In parts of Europe and the Near East **goats** are still used, both for their meat and their milk. The **venison** of the deer is still used in winter in our Northern States and Canada. Large numbers of **rabbits** are used as food in the Western States and in Australia, and **reindeer** meat is shipped in from Alaska. Large amounts of **poultry** are also used as food. What effects have modern methods of **refrigeration** had upon the transportation of meat?



Courtesy of the International Harvester Co.

FIG. 288.

Shorthorn "baby beef," all ready for the stock show. Such types are now raised for their meat.

Fish forms almost the only meat diet for a large part of the human race. The most important American food-fishes are the **salmon** on the Pacific Coast and the **cod** upon the Atlantic. The best fishes in the Great Lakes are the **whitefish** and lake trout. Herring, shad, and mackerel are the other very important salt-water fish, and perch and bass those most important in our rivers and inland lakes.

The stories told of fishermen's experiences on the Grand Banks of Newfoundland are no more thrilling than the stories of the adventures of the fish themselves. We usually think that salt-water fish live always in the ocean, but this is not true. An instinct as strange as the spring migration of birds causes such fish as the cod, salmon, and shad to swim up into rivers in search of quiet, fresh water. There they lay their eggs, and there the young develop. In their journey up the rivers of the Pacific Coast the salmon swim against the swift currents of rapids, and even climb up waterfalls, in their determination to reach the upper part of the stream. Some of them, torn by the rocks, succeed in getting through the rushing water and in escaping the nets of the fishermen. When the young "fry" are old enough, they swim down the streams to the sea, there to live as salt-water fish until the time comes for them to lay eggs (**spawn**) in their turn. They then repeat the dangerous, hard journey of their parents, generation after generation. **Salmon-canning** is a very important industry.

In order that the inland waters and the sea may be kept supplied with fish for human food, many **governments** hatch fish eggs. Young fish are guarded by law until they reach a certain size, and adult fish are protected from capture at the time the eggs are laid.

340. The Dairy Cow.— Since we have learned how valuable milk is as human food (see § 305), we realize what the dairy cow (Fig. 289) and the dairy industry mean to our health and prosperity. To millions of babies milk is almost the only food. It is of supreme importance, therefore, that milk shall be perfectly fresh, free from dirt and harmful bacteria, and rich in nutritive materials. Because milk is so nutritious, it is a breeding place for bacteria. In **cold** milk, however, bacteria cannot grow so rapidly. Hence the great need of **ice,** in hot weather, to save the babies from diseases that come in spoiled milk.

Dairying, like other kinds of farming, is a business (§ 291), and cannot be run unless it brings in a profit. It is of great importance what quality of cows is raised, and how much return they give. Experts in dairying have found out that the only safe way to judge a cow is by her product, the milk, as compared with the food she consumes. From the manufacturing point of view, a dairy cow is merely a **machine** for changing feed into milk. By weighing a cow's milk daily, by testing it for its per cent of butter fat, and by weighing the feed consumed, the farmer can know whether the cow is a profitable animal, or not. The **Babcock** test for butter fat is of great value to the milk industry. In this test a certain volume of milk is put into a narrow-necked bottle, some sulphuric acid (§ 246) is added to destroy the **casein** (the protein of the milk), and the bottle is then whirled rapidly in a **centrifugal** machine (§ 113). As a result the butter fat collects in the neck of the bottle, and its amount can easily be determined.

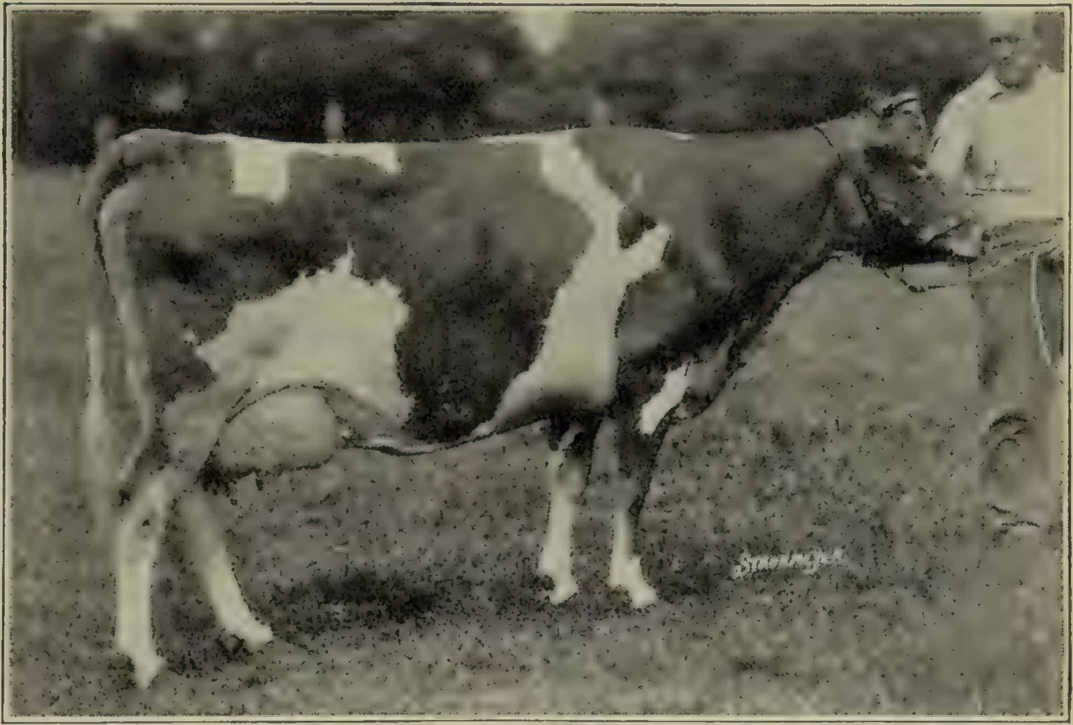


FIG. 289.
Countess Prue 43785, the World's Champion Guernsey cow, with a record of 18,626.9 lbs. of milk, containing 1,103.28 lbs. butter fat, in a year.

In order that the milk we use may be as good as possible, we must coöperate with the dairyman. If he knows his business, he milks the cows carefully, so that no dirt gets into the milk. He also **cools** the fresh milk, and puts it **at once** into clean, glass bottles, with tight, new covers, so that bacteria may not multiply rapidly in it. We should transfer the cold milk delivered to us **at once** to a cold place, and we should be careful to cleanse the cover and neck of the bottle before we pour out the milk.

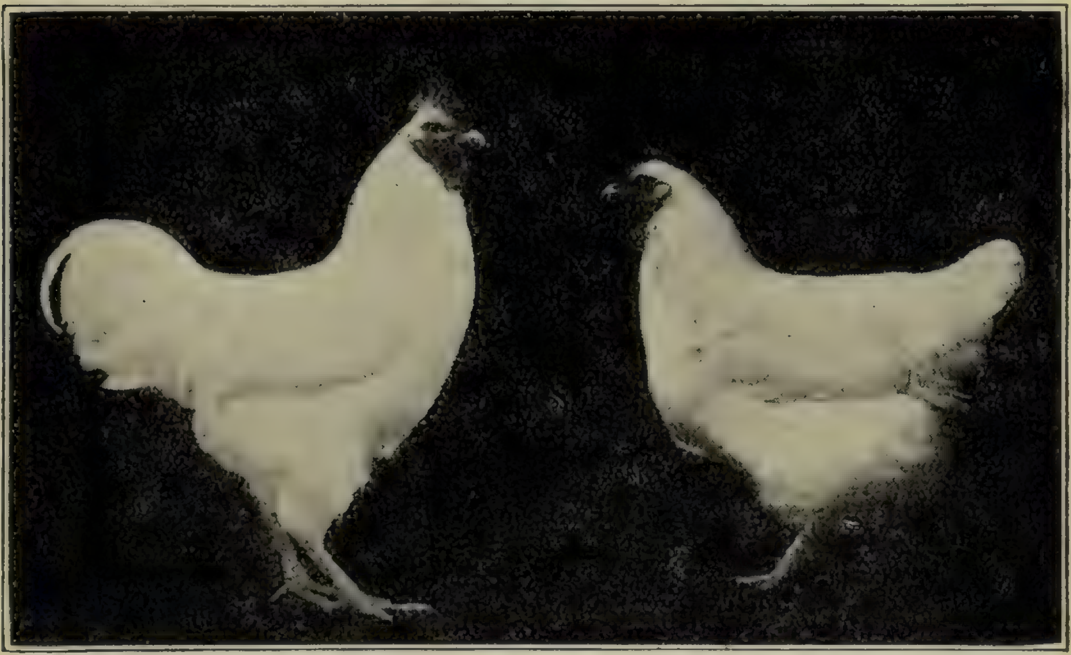
Courtesy of the Field Museum of Natural History.

FIG. 290.

Group of wild turkeys.

How did men develop cattle that give such large yields of milk and fine "cuts" of meat? The same careful **selection** was needed here as with cultivated plants (§ 326). Man has picked out the animals that seemed to have certain qualities which he desired, and then he has bred these animals, generation after generation, each time picking out the best ones. Thus he has obtained **thoroughbreds.** He has bred some **sheep** for their wool, others for their meat; some **horses** as racers, some as carriage horses, others as **draught** horses, to haul loads and do the heavy work of the farm. The kind of a **cow** that will yield excellent meat is different from one that gives a large amount of excellent milk. Even the milk-producing cows vary, according as the milk is selected for its butter fat, or for its **casein,** which goes into the making of **cheese.**

341. Birds as Food.— The most important domestic birds are chickens, ducks, geese, turkeys, and pigeons. Chickens and ducks are valuable for their meat, eggs, and feathers, turkeys and pigeons for their meat, and geese for meat and feathers. Feathers are a form of the epidermis, or outer skin, and correspond to the hair of animals. See § 53. Our **chickens** are probably descendants of the jungle fowl of the Far East. **Turkeys** are natives of America, and have, therefore, been domesticated only a comparatively short time. In some parts of the country the wild bird still exists (Fig. 290). The domestic turkey is still



Courtesy U. S. Department of Agriculture.

FIG. 291.
White Plymouth Rock cockerel and hen.

far from being tamed, for it wanders away to lay its eggs and to bring up its young, like its wild ancestors.

There are perhaps 20 or more **billions** of eggs produced by the hens of the United States in a year. The hen, like the cow, is a machine for changing her feed into our food. Some breeds of chickens are especially valuable for their **meat**; such are brahmas and cochins. Leghorns and minorcas are good **egg-laying** breeds. Rocks (Fig. 291), wyandottes, and Rhode Island reds are fair egg-producers and meat-producers. They are called "general-purpose" chickens.

Eggs are a very **nutritious** food and easily digested; they can be kept a long time, if **cold.** In **baking** they are used largely (aside from their food value) because they can be beaten into **foam.** This "sets" when heated, and makes the dough with which it is mixed light and easy of digestion.

Eggs "hatch" if kept warm for about 21 days. A heated box, or **incubator,** is often used in place of a mother hen. Eggs must be **fertilized,** or they will not develop into chicks. A careful chicken-raiser "candles" eggs, after they have been under a setting hen, or in an incubator, for 7 or 8 days; that is, he looks through the egg, using a strong light, to see what is happening inside the egg. If the interior is clear, he knows the egg is **infertile,** and there is no chick inside; but if he sees a dark mass, he knows that a chick is developing. A simple **candling box** (Fig. 292) may be made out of a pasteboard box (such as is used for breakfast cereals) with a hole for an electric-light bulb at one end, and one, for the egg, at the other end.

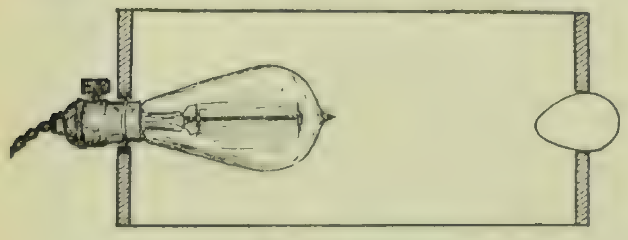
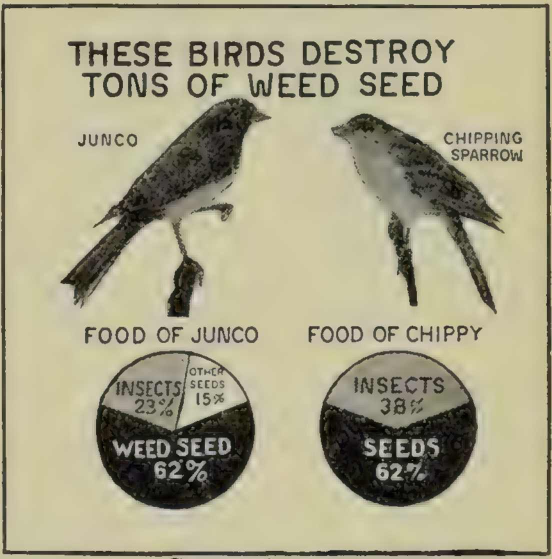


Fig. 292.
A home-made candling box for testing eggs.

342. Birds and Insects.— What do wild birds do for us? For one thing, we like birds for the **beauty** which they bring to our farms, forests, parks, and yards. We admire the plucky birds that remain with us through the winter, and we look eagerly for the return of those whose instincts carry them far to the south each autumn. What could make up for the loss of their graceful, often brilliantly colored bodies, their cheerful songs and calls, and their dashing flight? Then we admire birds for their wonderful **nests**, and for the tender care they give their young. Think of the nesting parent birds during the spring storms, and how faithfully they cover their eggs and their young, and face pelting rain and hail, crashing branches, and flashes of lightning, for the helpless things entrusted to their care! Then, when the young are ready to fly, how faithfully the older birds teach them, and protect them from cats and snakes and similar enemies, until they can fly alone! Writers of all time have told of the faithfulness of bird-parents to their young.

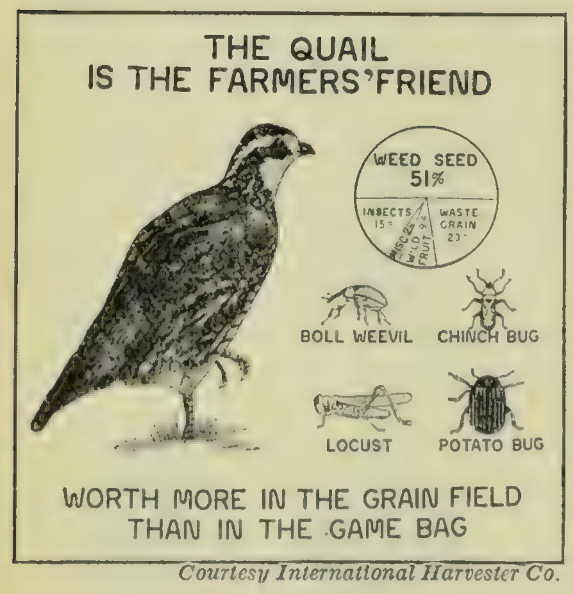


Courtesy International Harvester Co.

FIG. 293.
How the junco and chipping sparrow help the farmer.

It is only recently that people in general have learned how **useful** birds are to us. People have known that robins like our cherries, and that quails eat some grain, but they have not known how generously these birds pay for their meals. This knowledge has come to us only from a scientific study of what birds really eat (Figs. 293 and 294). No one likes to **weed** the garden. The birds, especially our song birds, eat enormous quantities of **weed seeds,** and so prevent their germination. The well cultivated, fresh soil of the garden is just the place in which hosts of weeds thrive wonderfully; in fact, a garden is really an invitation to all the weeds of the neighborhood. But the birds' help to the farmer and gardener does not stop with the eating of weed seeds. The fresh, tender growth of the garden and farm is also an invitation to the **insects** of the neighborhood, and it is with insects that man has his hardest struggle in raising crops for himself and his domestic animals. The most powerful agency at work in **destroying** insects is the birds.

Only a **few** birds are really harmful to us; these are the English sparrow, the cowbird, two species of hawks, the great horned owl (but not the other owls), and a very few others, perhaps. Even crows eat many destructive field mice and cutworms. In order to learn what different birds eat, and to find out which are the really harmful birds, scientists are obliged to kill a few birds of each kind, and to examine the "crop" in which the bird stores its food before digestion. Then it is possible to count the insects, weed seeds, and grain which the bird has eaten.



Courtesy International Harvester Co.

FIG. 294.
The quail pays well for the waste grain it eats.

343. Protection of Birds.— If people could only understand the value of a bird, such as a robin, they would not kill it for the tiny bit of meat it yields; yet hundreds of thousands of robins are sacrificed in this foolish way each summer. How much better it is to do our "shooting" with a camera instead of with a gun, and to get pictures of birds' eggs in their nests, and of the young fledglings, week after week, until they leave home, and launch forth into the bird world for themselves!

We would do a great deal for birds, if we could protect them from **cats.** If no stray cats were permitted to live, and if house cats were cared for, the danger to birds would be much smaller. If house cats were not let out in the morning until they have been fed, they would do much less harm, for they do their bird hunting chiefly in the early morning. One pet cat, well fed at home, was known to have killed 58 birds in one season; what may not stray cats, with no regular source of food, be doing!

Bird houses and bird baths are excellent means of attracting birds about our homes. A bird house should be set upon a strong pole at least 8 feet above the ground, and should be protected, at a height of about 5 feet, by a strip of tin or zinc 18 to 24 inches wide going entirely around the pole. The smooth metal strip prevents a cat from climbing up to the bird house (Fig. 295). **Bird clubs** serve to educate people regarding the interesting life habits of birds and their value to the community.

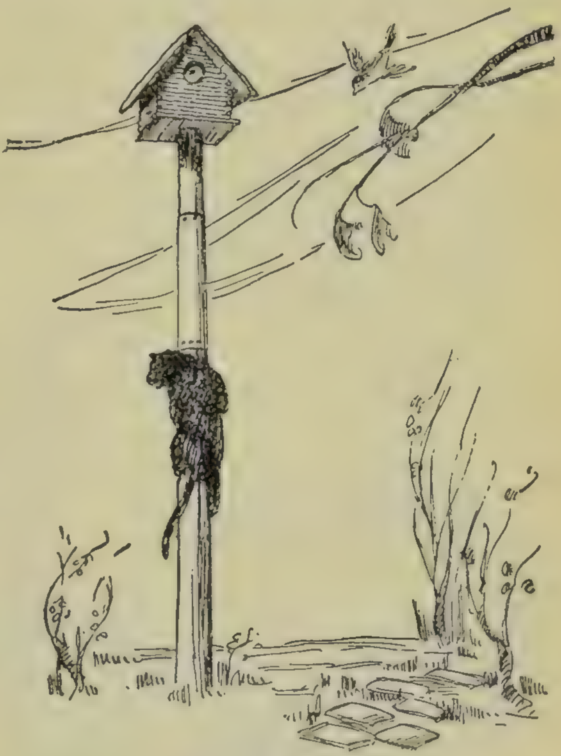


FIG. 295.
The cat cannot climb beyond the metal strip on the post.

344. Structure of Insects.— As we already know, insects include May beetles, potato beetles, crickets, ants, bees, wasps, flies, mosquitoes, butterflies, moths, and many more besides. The name, **insect,** means "cut into parts," and is given to these creatures because of the many **joints,** or segments, in their bodies. The main divisions of an insect's body, as of our own, are **head, thorax** (chest), and **abdomen** (ăb-dō′mĕn). The insect's abdomen consists of many jointed rings. The legs of an insect, and its wings, if it is a flying insect, are attached to the thorax. In **spiders** the head and thorax are not separate, but one structure. The **respiration** of insects takes place in tube-like air passages in the different segments of the body.

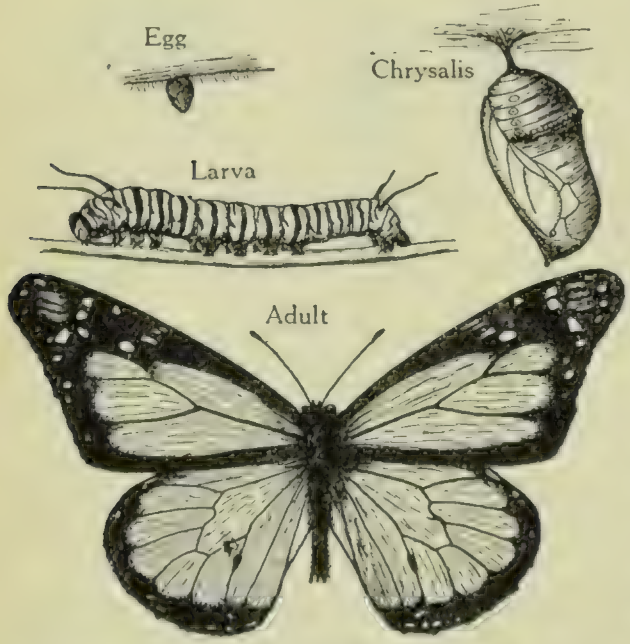


FIG. 296.
Successive stages in the growth of a monarch butterfly.

Scientists distinguish about 10,000 different kinds, or species, of birds, and about 12,000 species of fishes; but of insects there are between 200,000 and 300,000 different species. When we remember how rapidly insects multiply, we realize how serious a matter the loss of our insect-eating birds would be. Thus, it has been calculated that **one pair** of Colorado potato beetles, if left to multiply undisturbed for **one season,** would become an army of 60,000,000. What would become of the potato crop, if this were the case?

In spite of the damage which the class of insects does to our crops and to our domestic animals, we cannot help being interested in their life story, and in the wonderful stages which some of them, especially butterflies and moths, go through, as they grow from tiny eggs into the beautiful, adult creatures which we know (Fig. 296). We may call these stages: (1) the **feeding** stage; (2) the **resting** stage; and (3) the **adult,** or egg-producing stage. Unless we have actually watched the operation, it is hard for us to believe that so complete a change, or **metamorphosis** (mĕt′ă-mŏr′phō-sĭs) is possible. That butterflies and moths, which are so beautifully marked, which visit flowers for nectar, and aid plants in fertilization (§ 319), were ever the **caterpillars** that devour our crop plants and spoil our fruit, seems incredible.

The changes of the **monarch butterfly** illustrate those of the others. The eggs are laid upon the milkweed. The caterpillar that emerges from the egg devours the milkweed's leaves, and grows enormously. When it has stored away enough rich food, it becomes quiet, and attaches itself to the under side of a leaf or stem. Then a **change** takes place. The body shrinks, and becomes surrounded by a thin, translucent skin. The creature inside can be seen plainly. Finally the skin breaks, and the butterfly comes out. It rests until the tubes of its wings are filled with air, and the wings are spread; then it flies away.

The caterpillar, or "worm," is the **larva**; in the resting stage we call it a **pupa,** or **chrysalis** (krĭs′ă-lĭs); the adult is called the **imago** (ī-mā′gŏ). **Moths** go through the same stages as butterflies, except that the caterpillar spins a warm **cocoon** about itself. We often see the cocoons of the beautiful **cecropia** moth on trees in the winter, waiting for the spring, when the creature completes its metamorphosis.

345. Insects as Friends and Foes.— How can we get rid of these pests that destroy our crop plants? For much of the work of caring for our crops we must depend upon **birds.** In addition, the modern farmer uses substances poisonous to the insects—**insecticides** (ĭn-sĕkt′ĭ-sīdz). Thus, to prevent an army of grasshoppers or locusts from invading his field, the farmer scatters around the edge of the field a pasty mass of molasses and bran, containing also a little of an arsenic compound. To combat potato beetles he puts a mixture of Paris green and water upon the leaves.

Biting insects, such as the elm beetle, the potato beetle, the locust, and the voracious larvae of many moths and butterflies, eat the whole leaf; for these we put on the leaf a poison, such as Paris green or lead arsenate (ăr′sĕn-āt), so that the insect will eat the poison along with the leaf. The wise farmer sees to it that the amount of poison used is not enough to kill the birds that eat the dead insects. To protect fruit trees we use **sprayers** that force the poisonous solution or **emulsion** (§ 253), in a fine mist, over the tree.

Sucking insects, such as plant lice and scales, do not eat the whole leaf, and cannot, therefore, be easily killed by poison placed on the outside. For them we need a liquid that closes their breathing pores (§ 344). An emulsion of kerosene and soapy water, especially if it contains **nicotine** (nĭk′o-tĭn) **sulphate,** destroys many such insects. What is the source of nicotine?

Borers form a **third** class of destructive insects. The larvae of some of them have such strong mouth parts that they can cut their way through wood. Often one can **hear** them at work inside a tree.

Another method of insect control that has been tried is to use one insect to devour **another.** Thus the lady beetle destroys the orange scale.

The insects that are most interesting of all are **bees, ants,** and **wasps,** some of which have very highly developed social organizations. Men will never cease to marvel at the way in which honey bees make their houses, care for their young, store food, and act like the members of a community, with duties to the colony, or **swarm,** to which they belong. The **ruler** of the swarm is the **queen.** She lays the eggs that perpetuate the swarm. Some eggs develop without being fertilized; these form the male bees, or **drones.** The fertilized eggs produce female bees, but only a few of the females, the **queens,** become capable of laying eggs. The greater part of the females remain undeveloped, and, as **workers,** do all the work of building the honey cells, providing the honey, and feeding the young larvae, or **grubs,** when they hatch. When the queen bee dies, the workers feed one of their number with a special food, so that she develops into a queen.

Ants form colonies, some of which are quite as wonderful as those of bees. Some ants act as **soldiers,** and protect those that work. Certain ants capture other ants, and make **slaves** of them. Other ants carry, or lead, **plant lice** to good feeding places on the leaves of plants, and are then rewarded by the sweet liquid which the lice produce. We often disturb an ant colony when we raise a stone or log. Then we may see the ants anxiously carrying away their young larvae, which look like "rice grains."

346. Flies.— Flies must be looked upon as the enemies of public health. The eggs are laid in the body wastes of animals, and produce white larvae, called **maggots.** After about a week of rapid feeding, the larva of the housefly forms a shell about itself, in which it undergoes its metamorphosis. In another week the adult fly comes forth (Fig. 297).

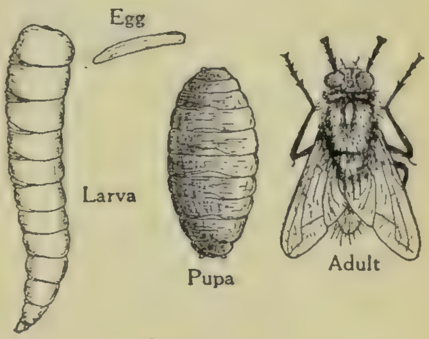


FIG. 297.
Stages in the growth of a housefly.

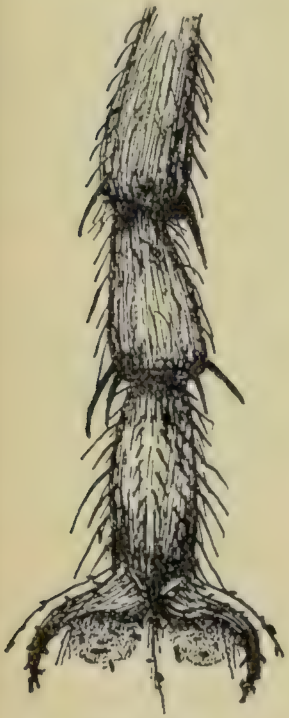


FIG. 298.
The foot of a fly (magnified); an efficient structure for collecting germs.

Flies feed in all manner of dirty places; they enter sickrooms, and come away loaded with disease germs. Germs are likewise present in the discharges of the fly's body—"fly specks." We should certainly keep flies away from our tables, dishes, food, and faces, by screening the house and destroying any flies that get inside. **Flytraps** are very useful. Especially should we protect little children from flies.

The adult fly is largely what we make it. It does not travel far. Flies will not breed, if there are no dirty places, such as manure heaps, in which they can lay their eggs. They will not carry disease germs (Fig. 298) if we destroy germs that come from sickness. Flies will not find food around our houses if garbage is carefully covered, removed, and destroyed. So to get rid of the fly and its dangers, we should keep our neighborhood **clean.**

347. Mosquitoes.—The mosquito is not only a **nuisance,** but also a **disease-bearer.** The egg is deposited in water (Fig. 299), and hatches to form a "wiggler," the **larva,** which swims about. The larva breathes through the end of its "tail," and must come to the surface for air. We can kill it by putting a film of kerosene upon the water, to cut off its air supply. Small fish eat the wigglers in a pond. The wiggler sheds its skin often, and changes into a **pupa.** Finally the **adult** mosquito emerges.

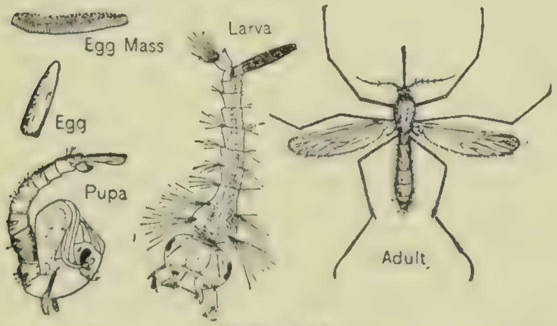


FIG. 299.
How a mosquito develops from the egg.

Mosquitoes, like flies, are **home products.** They live near the place where they were hatched. To get rid of them we must not allow open cisterns, wells, rain barrels, or watering troughs to be in the neighborhood. Sagging eaves troughs, broken crockery, tin cans, or anything that holds water, give the mosquito its opportunity. The **catch basins** of city streets often act as mosquito breeding places.

One kind of mosquito (**anopheles**; ăn-ŏf′ē-lēs) carries **malaria**; another carries **yellow fever.** If the malaria-carrying mosquito inserts its sharp **proboscis** (prō-bŏs′ĭs) into the body of a person having the disease, the germs of the disease enter the mosquito's body along with the blood consumed. There they multiply, and in due time infect another person bitten. The mosquito that carries **yellow fever** is **stegomyia** (stēg-ō′mĭ-yă). This fever was almost entirely driven out of Cuba and the Panama Canal Zone when the breeding places of the mosquitoes were destroyed, and when persons sick with the disease were screened off with great care.

348. Summary.— His **domestication** of plants and animals led man to build communities and nations.

The eastern hemisphere had the better **beasts of burden.**

Cold storage and **transportation** have changed our meat supply.

Scientific methods have greatly improved **dairying.**

Domestic birds are valued for their meat, eggs, and feathers.

We should **protect song birds** because of their beauty, their songs, their care of their young, and their destruction of weed seeds and harmful insects.

Insects are man's greatest enemies in his effort to raise and preserve plant food.

Ants, bees, and wasps live in well developed **societies.**

Flies and mosquitoes often spread disease and should be destroyed.

349. Exercises.— 1. The Latin word for money, **pecunia,** from which we get "pecuniary," comes from a word meaning **cattle**; why?

2. Name some uses of fishes besides as food.

3. Our word **pen** comes from **penna,** a feather; why?

4. Name several climbing, perching, swimming, and wading birds.

5. In which stage of insect-development is the silkworm? Is the adult of the silkworm a moth, or a butterfly?

6. Out of what part of the plant does the bee form honey?

7. Why, and from what, does a spider spin its web?

8. What animal skins have been used as bottles? As paper substitutes? As book coverings? As clothing?

9. What part of the milk is present in cheese, butter, and whey?

10. What harmful insects live in your locality?

350. Projects.— 1. Report on how many eggs your city uses in a year, and where they come from.

2. Prepare a report on the uses of the hair of animals.

3. Prepare a paper on protective coloring and other mimicry found in animals.

4. Bring to school some cocoons of the cecropia or other moths, and show their development.

5. Show the class a collection of birds' eggs borrowed from a museum.

6. Show the class a collection of butterflies.

7. Arrange a debate on: Resolved that the domestic cat does more harm than good.

8. Arrange with a chemistry student to show the class the Babcock test for butter fat.

9. Keep a record of the winter birds of your locality.

10. Keep a calendar of the dates of the spring migration of birds in your community.

11. Prepare a paper on the conquest of yellow fever.

12. Prepare a paper on the preservation of the native animals of North America.

13. Report on how many eggs a hen should lay to pay a profit.

14. Make an egg-tester and candle an incubated egg for the class to show the development of the chick.

351. References.— DOWNING: *Our Living World.* Farmers' Bulletins of the U. S. Department of Agriculture. INTERNATIONAL HARVESTER CO.: *Pamphlets.* MAETERLINCK: *The Life of the Bee.* ROGERS: *Wild Animals Every Child Should Know.* SHARP: *Wild Life Near Home.* WATERS: *The New Agriculture.*

CHAPTER XX

THE HUMAN BODY

352. The Structure of the Body.— The human body, like the bodies of other animals, is built according to a **plan.** Man is a **vertebrate,** that is, his framework is on the **inside,** and has the form of a bony **skeleton.** Man belongs to the highest group of vertebrates, the **mammals.** In the four-footed mammals we distinguish two spaces, or **cavities**: (1) one along the **back,** consisting of the brain space, or skull, and the long narrow space, or canal, inside the spinal column; (2) the large space underneath, containing such organs as those of respiration, circulation, and digestion. The upper space is the **dorsal cavity**; the lower one, the **ventral cavity**. A muscular wall, the **diaphragm**, divides the ventral cavity into two parts. The front space is called the **thorax**, or chest; the rear space is the **abdomen.** In man, notwithstanding his erect position, these same divisions exist. His thorax contains the lungs, the heart, some large blood vessels, a few glands, and the esophagus (ē-sŏf′ă-gŭs), by which food is carried from the mouth to the stomach. Below the diaphragm is the abdomen, which contains the stomach, intestines (bowels), liver, kidneys, pancreas, spleen, and other organs. The thorax and abdomen together form the **trunk.**

The science that deals with the **organs** of plants and animals, and with the **functions** of these organs, is called **physiology.**

353. A Living Cell.— We have learned that some plants, like pleurococcus (§ 322), consist of a **single cell.** There are also one-celled animals, such as the **ameba** (ă-mē′bă), a tiny creature found in muddy pools (Fig. 300). When examined under the microscope, the ameba shows a peculiar ability to change its shape and move about. The ameba consists of a **cell of protoplasm.** Near its center the cell is grainy; this region is the **nucleus** (nū′klē-ŭs). There are no **organs.** The creature moves by extending the cell wall at any region into a projecting **lobe**; the contents of the cell then flow into the lobe. The lobes are called **false feet.** The ameba has no mouth. It feeds by extending two lobes around a bit of food, and then drawing away the cell wall; the protoplasm simply encloses the food. The ameba **excretes** (throws out) waste food-particles merely by moving away from them. When materials go through the cell wall, no opening is left, just as there is no break in the film of a soap bubble when a needle is put through it.

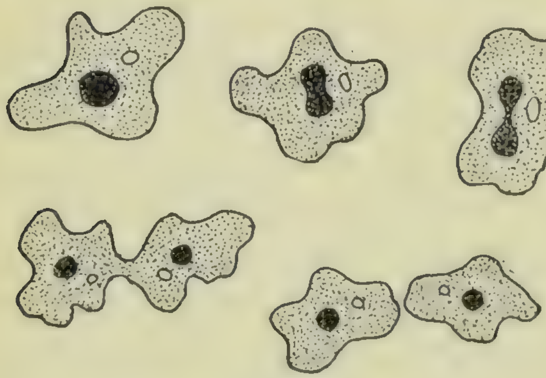


Fig. 300.
An ameba in the process of division.

The **reproduction** of the ameba is also very simple. The nucleus divides itself into two parts, about half of the protoplasm groups itself about each nucleus, and at the line thus formed the cell divides; there are now **two** amebas instead of one. As in the case of pleurococcus, this is **reproduction by cell-division.**

The human body, like the body of any plant or animal, is composed of **cells**. These cells are of **living protoplasm**, and consist of walls and cell contents. Like the ameba, each cell carries on the fundamental processes of life. It feeds, and it rejects waste. The body's cells also reproduce themselves by **cell-division**. However, unlike the cells formed by the division of an ameba, the new cells of our bodies do not separate, but remain together. In this way the whole body can grow, and new cells at once replace those that wear out.

Since the cells of our bodies form a large community, a **division of labor** is necessary. So we find special groups of cells doing special kinds of work. A **group** of cells in which all the cells do the same kind of work is called a **tissue.** Out of certain tissues, or mixtures of tissues, the organs of the body are made. The muscles contain **muscle tissue**, or groups of muscle cells, and the brain contains **nerve tissue**, which consists of nerve cells.

One form of tissue is called **connective tissue**, because it connects other cells. Its cells have slender, fine branches which extend between the other cells, and hold all together. So **muscles** really consist of muscle tissue held together by connective tissue.

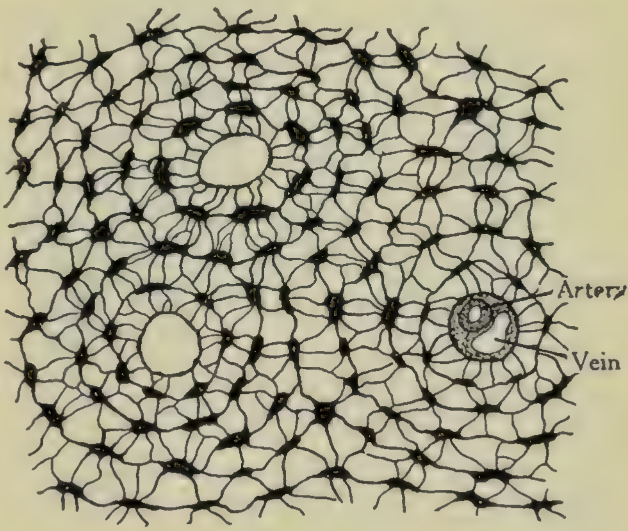


FIG. 301.
Bone cells (magnified) with canals for nerves and blood vessels.

354. Structure of Bones.— Bones are made up of branching, interlaced cells (Fig. 301) of connective tissue, stiffened with limestone and calcium phosphate (§ 301). The limestone is about $\frac{2}{3}$ of the weight of the bone. Among the bone cells there are tubes, or "canals," containing blood vessels and nerves. The outside layer of a bone is very compact, and the whole bone has a tough covering of connective tissue—the **periosteum.** The animal matter (that is, the connective and other tissues) of a bone are destroyed by burning. The ashes contain the mineral part. The limestone we can remove by soaking the bone in some dilute acid (§ 247). The tough connective tissue will remain, but the stiffening will be gone. Long bones have cavities. They thus have the greatest possible strength, with the least possible weight.

Cartilage is a form of connective tissue. It contains very little limestone, and forms part of the skeletons of young animals. As limestone is added, the cartilage becomes more hard, but also more brittle. However, all the cartilage in the body does not become hardened. Some remains at the end of almost every bone, to diminish friction, and to prevent the jarring of one bone against another.

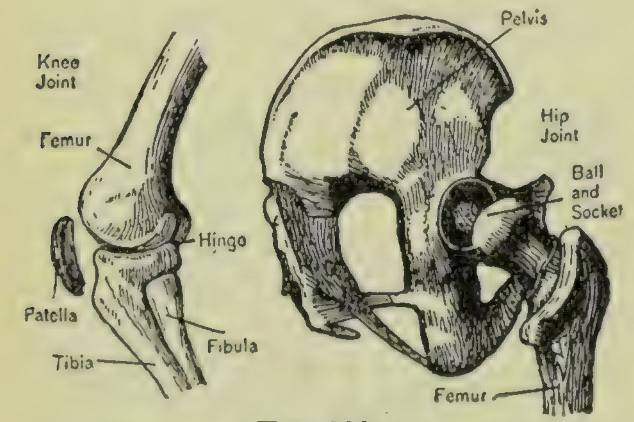


FIG. 302.
Hinge and ball-and-socket joints.

355. Joints.—A joint is a place where bones come together. Some joints are intended to be bent freely; these are **flexible**, or movable, joints. Some are not arranged for bending; these are **inflexible**, or immovable, joints. Some of the bones of the skull are held together in inflexible joints.

Between **inflexible** joints there is usually a layer of cartilage or of material much like it. Its use is shown admirably in the backbone, where it forms **pads** between the vertebrae. These pads permit the backbone to be bent somewhat, and act as cushions to relieve the skull as much as possible from the jar caused by walking and running.

At **movable** joints the bones are held together by tough bands, called

ligaments, and the ends of the bones are smooth and round. When muscles pass over joints, they also assist in holding the bones together. We distinguish **three** principal kinds of movable joints (Fig. 302):

(1) Those in which the movement is in **two opposite directions** only, as in an ordinary **hinge**; these are called **hinge joints**. The knees, elbows, and fingers have hinge joints.

(2) Those that can be moved **in any direction**, as the arm can at the shoulder. Such joints have the rounded end of one bone fitting into the socket of another, and are called **ball-and-socket** joints.

(3) Those in which one bone glides over another (**gliding** joints).

356. The Skeleton.— The skeleton of man (Fig. 303) is planned for lightness as well as strength, and its bones are admirably fitted together. It forms a framework for supporting not only the soft organs inside the skeleton, but also the muscles, fat, and skin which cover the bones and give the body its outer form.

The bones of the **head** form a protective case for the brain, and provide sockets for the eyes, and other hollows for the nose, tongue, teeth, and ears. The skull, or **cranium**, has also a special bone to rest upon, at the top of the backbone, or **spinal column.**

The **chest**, or thorax, is a box for the lungs, heart, and other organs (§ 352), and for the attachment of the **diaphragm**, which forms the **bottom** of the chest. The **ribs** form the **sides** of the chest; they are attached to the backbone. Seven pairs of them are joined, in front, to the **breastbone**; three more pairs are joined to the lowest pair of true ribs (those attached to the breastbone); and two pairs of ribs are not attached in front. These last are **floating** ribs.

The four **limbs** have 30 bones each. The bone of each upper arm is attached, by a ball-and-socket joint, to its **shoulder blade**; the **collar**

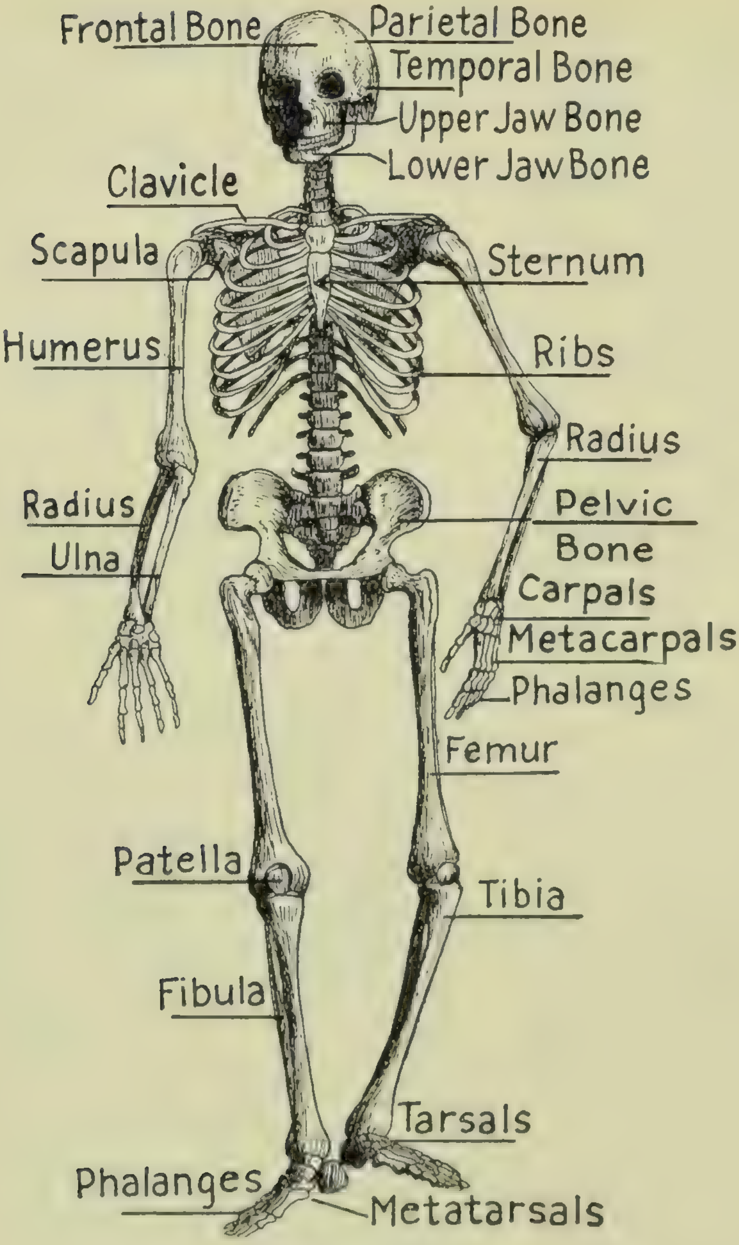


FIG. 303.
The skeleton and its parts.

bones hold the shoulder blades in place. At the bottom of the backbone there is a group of four bones. These support the abdomen, and two of them, the **hip bones**, contain the sockets of the ball-and-socket joints by which the upper bone of each leg is attached to the body.

There is a **kneecap** in the leg, and no bone like it at the elbow; but there is one bone more in the wrist than in the ankle; hence the bones in the arm and the leg are equal in number.

Bones of Head		**Bones of Trunk**				**Bones of Limbs**	
Skull	8	Backbone	24	Breastbone	1	Arms	60
Face and tongue	15	Base of abdomen	4	Collar bones	2	Legs	60
Ears	6	Ribs	24	Shoulder blades	2		120
	29				57		

Total number of bones......206

357. Muscles and Tendons.— The muscles are the organs that move the animal body (Fig. 304), and at the same time cover the skeleton with rounded flesh. They constitute the **lean** part of meat. Muscles are made up of long cells. **Connective tissue**, in the form of a white, skin-like membrane, is present between the muscle cells, and also holds the muscles in **bundles**.

The business of muscles is to **grow shorter** (to contract) when commanded. By the shortening of its cells, the muscle itself grows shorter. At a movable joint two muscles usually act **in opposition** to each other, like two springs on opposite sides of a door. If one muscle shortens itself, the other grows longer. The two give a forward and backward motion to the bone, like that which we see when we raise and lower the forearm.

Tendons are the extensions of the connective tissue of muscles; they bind muscles to bones. The tendons are sometimes very long, and attach a muscle to a bone **at a distance.** This is true in the hand. The thick muscles that move the hand are in the forearm, while the hand itself is slender and skillful. The long tendons that extend to the hand and the foot are held down, near the bones, by means of circular bands (**ligaments**) at the wrist and ankle.

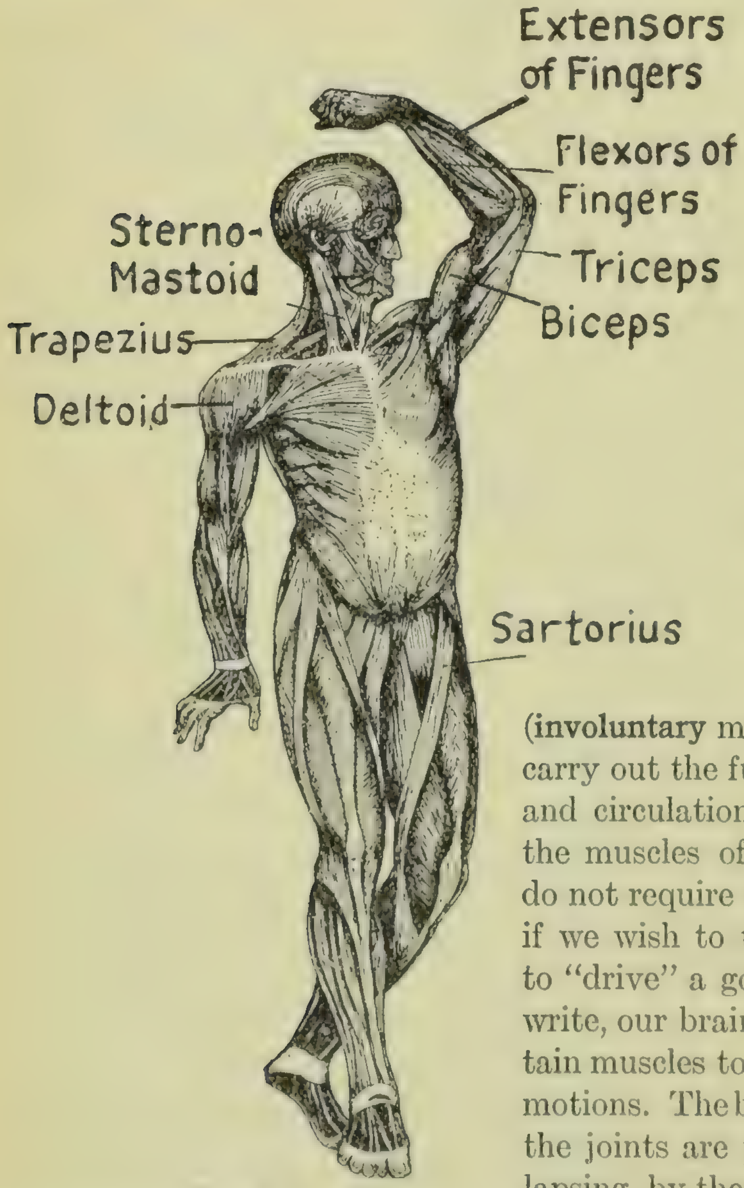


FIG. 304.
The surface muscles of the body.

The bones act as **levers** (§ 263). To lift your **forearm** (Fig. 247, § 264), the **biceps** muscle of the upper arm contracts, and pulls upon the **radius** bone a few inches below the elbow. The **fulcrum** is at the elbow.

Some muscles are under the control of the will (**voluntary** muscles), and some are not (**involuntary** muscles). Our bodies carry out the functions of digestion and circulation without our wills; the muscles of heart and stomach do not require our attention. But if we wish to throw a baseball, or to "drive" a golfball, or to sew or write, our brain must call upon certain muscles to produce the proper motions. The body is held erect, and the joints are prevented from collapsing, by the action of a multitude of muscles.

358. Care of Bones and Muscles.—When bones are broken, it is not only the mineral matter that breaks, but the connective tissue, and the blood tubes and nerves as well.

When the broken pieces are held together by bandages and splints, new cells of connective tissue unite the broken edges, and restore the connections of the nerves and blood vessels. The filling of the connective tissue with minerals is the slowest part of the healing process. When this takes place, the bone is said to "knit" together. As a person grows older, more mineral is deposited in the bones, and they become more brittle. They therefore break more easily than in childhood, and do not unite so readily if broken.

When the bones of a joint are separated, the bones are said to be **dislocated**, or "out of joint." In this case the ligaments and muscles at the joint are probably torn. In a bad dislocation the muscles may draw up the bones and prevent them from going back into place for some time. The physician then puts **splints** on the joint to hold it stiff, until the ligament has time to grow together again. The chief difference between a **sprain** and a dislocation is that in a sprain the bones are not separated. **Tuberculosis** often attacks the joints. At the hip it produces "hip disease."

The chief injuries to muscles come from either **overwork** or **underwork.** Most students take too little exercise, and are content to let others play, while they themselves look on. The body should get **daily** exercise, best out of doors. One should exercise until he just begins to be a little tired; then he should rest. By gradually increasing the amount of our exercise, all of us can build up vigorous bodies. But exercise is only one of many necessary hygienic measures. We must have good food, and long hours of sleep, and we must avoid alcohol and all other harmful stimulants.

359. Organs of Digestion; Glands.— The tube through which food is passed for digestion is called the **alimentary canal**, or **digestive tract.** It consists of the mouth, pharynx (throat), esophagus (gullet), stomach, and the small and large intestines. It is about 30 feet long.

In order to digest food, liquids pour upon it in the mouth, the stomach, and the intestines. The liquids are taken out of the blood for this purpose by organs called **glands.** The origin of glands is as follows:

The alimentary canal, as well as the windpipe and lungs, is lined with **mucous membrane.** This begins at the lips and is a continuation of the skin which covers the outside of the body. It is pink from the network of blood vessels beneath it, and produces a thin, clear liquid called **mucus.** From this liquid it gets its name. The surface of the mucous membrane is made up of a layer of flat cells, called **epithelial cells.** Now, glands are made by the **folding in** of epithelial cells in tubes or pockets (Fig. 305). Blood vessels and vessels containing **lymph**, a substance much like blood (§ 379), are all about the glands; hence it is only necessary for the epithelial cells to take what material they want from the blood. They then give off this material to the gland pockets, and from the pockets it is poured out into the organ for which it was intended. A gland separating a liquid from the blood is said to **secrete** the liquid, and the liquid is called a **secretion.** The glands that secrete the digestive juice of the mouth are called **salivary glands**, and the secretion is **saliva.** The **gastric glands** secrete **gastric juice** for the stomach.

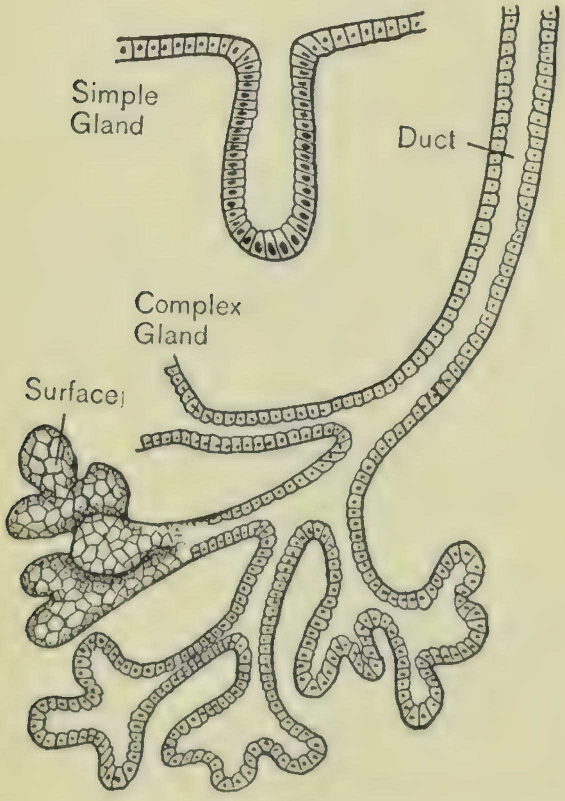


FIG. 305.
Diagrams of simple and complex glands.

360. The Mouth.— At the beginning of the digestive tract is the mouth. It contains the nerves of taste, while just above it, in the nose, are the nerves of smell. These two senses therefore pass upon the quality of the food at once. In the mouth the food is broken up into bits (chewed, or **masticated**) by the teeth. During chewing, the glands of the mouth secrete saliva; the mouth "waters." They often secrete it before food gets into the mouth; the odor or thought of food is enough to put them into action. The tongue rolls the food about in the mouth, so that the teeth may chew it again and again. Finally, when we wish to swallow the food, the tongue pushes it back to the opening of the throat, or pharynx.

Saliva consists chiefly of water; this moistens the food thoroughly before swallowing takes place. Some of the **solution** of the food also gets to the nerves of taste. The saliva is, however, more than water: it has an **alkaline** reaction (§ 248); it contains certain salts, also **ptyalin** (tī′ă-lĭn), a **ferment**, or **enzyme**. Ferments **by their presence** bring about chemical changes (§ 103).

Ptyalin begins the change of starch into sugar; hence a cracker becomes sweet when chewed. There are three pairs of salivary glands in the mouth: one pair just under the tongue; another behind the corners of the lower jaws; a third pair in front of the ears.

The tongue is a flat, movable organ made up of muscular tissue. The back of it is attached to the bottom of the mouth. It has **nerves of touch**, like those of the finger tips, and also nerves of taste.

The cheeks and lips are made up of thin muscles covered with skin on the outside and with mucous membrane on the inside.

361. Our Teeth.— The adult man or woman has 32 teeth, set into sockets in the jaw bones (Fig. 306). The teeth are of **4** kinds, called **incisors, canines, bicuspids,** and **molars.** There are 2 incisors ("cutters") in each half of each jaw. They are flat, sharp teeth used for biting off pieces of food. Next to the incisors is the canine, or "dog," tooth. This is sharper than the other teeth. In the dog and other carnivorous animals it forms the tusk, or tearing tooth. The fourth and fifth teeth are the bicuspids, so-called because each has 2 cusps, or points. The sixth, seventh, and eighth teeth are the molars, or grinding teeth.

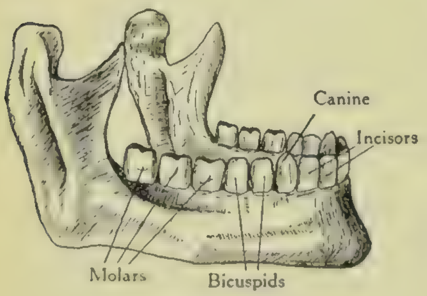


FIG. 306.
Teeth of lower jaw. How many are there?

The child's first set of teeth ("milk teeth") is temporary. There are 20 in the set. When the child is 6 or 7 years old, the first permanent teeth appear. The molars farthest back in each jaw are "cut" last, and are called the "wisdom teeth."

A tooth consists of a **crown** of very hard **enamel**, and a **neck** and **root** of material called **dentine.** The roots are covered with "cement." The interior of the tooth is called the **pulp cavity**; it contains the nerves and blood vessels of the tooth. The teeth are precious, and ought to be given every care. They should be cleaned, every day, with a soft brush, and if cavities are formed they should be filled by a good dentist. Hard substances, such as nuts, thread, and brittle candy, should not be bitten; for they may break the enamel. If bacteria get into the interior of the teeth, they cause a rapid decay.

362. How We Swallow.— When food is ready to be swallowed, the tongue pushes it back to the **pharynx** (Fig. 307). This is a muscular tube, about 4 inches long, having several openings. At its top there are two openings into the nose and one into each ear. The openings leading to the nose can be closed by the **soft palate**, which rises up against them. The opening between the pharynx and the mouth can be closed by two upright muscles, which come together like the halves of a sliding door. In passing from the pharynx, food must go over the "wind-pipe," or

trachea. We should soon be strangled if food went into our windpipe; hence the larynx, at the top of the windpipe, is closed by a cover, called the **epiglottis.** When the food is in the pharynx, and the openings to the nose, mouth, and windpipe are closed, the upper muscles of the pharynx contract above the food, forcing it downward into the **esophagus.** This is a tube about 9 inches long, lined with mucous membrane, and provided with circular and with lengthwise muscles. The esophagus muscles contract above the food, and force it down into the stomach.

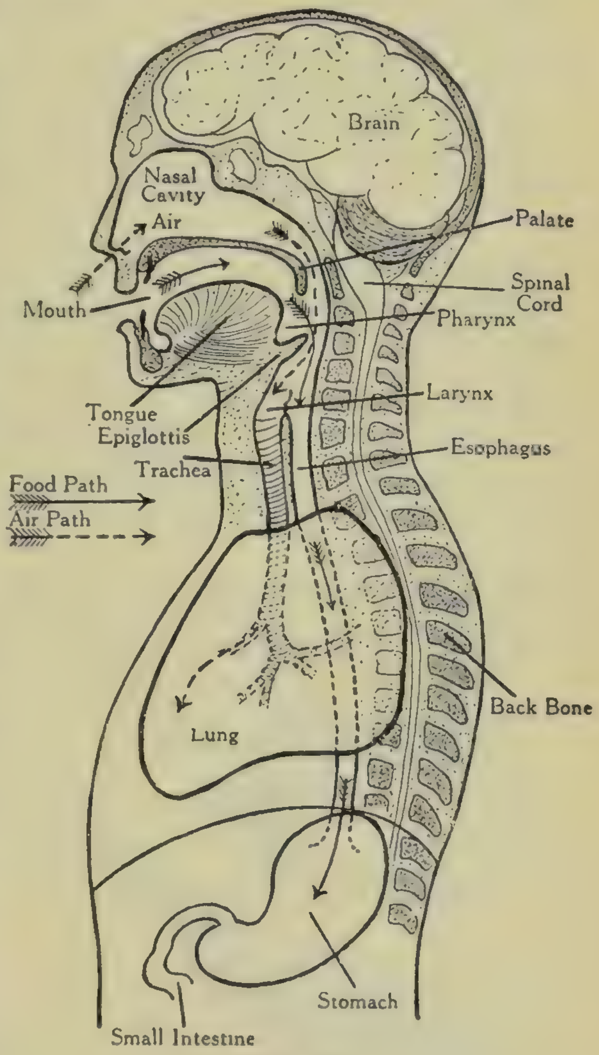


FIG. 307.
The routes of food and air in entering the body.

363. Exercises.— 1. What advantages has the internal skeleton of vertebrates over the hard external covering of insects? What disadvantages?

2. What advantages does man gain from his erect position?

3. Name several levers in the body.

4. How could you find out how much of the weight of a bone is due to mineral matter?

5. What devices are there in the skeleton to prevent the jarring of the softer parts of the body?

6. What kind of joint is there in your neck that makes it possible for you to shake your head? To nod "yes"?

7. What is the effect of high heels upon the position of the body in walking?

8. What kind of joints do the fingers have? What kinds has the thumb? What are the structures in the hand that make it so skillful?

9. Why does your head nod when you doze in your chair?

10. Do you think you are taller at night, or in the morning?

11. Give the reasons why sleep rests the body.

12. We are told that milk, and cereals such as oatmeal, are good for young children, because they assist in bone making. Why?

13. Why do stones, sand, and glass have no taste?

14. Why is the tongue provided with nerves of touch?

15. Why should a child's first teeth be cared for, even though they are soon to be replaced by the permanent set? Why ought we to be careful about bringing cold food, such as iced water ice cream, and cold melons, in contact with the teeth?

364. The Stomach.— The esophagus lies against the backbone, and passes through the thorax into the abdomen. The stomach, at the lower end of the esophagus, is wholly within the abdomen, on the left side, and partly under the ribs. It is about a foot long and about 4 inches in diameter. The stomach is really an expansion of the digestive tract, like a lake formed by the widening of a river. The opening (**pylorus**) from the stomach into the small intestine is closed by a muscular **ring** while digestion is going on in the stomach.

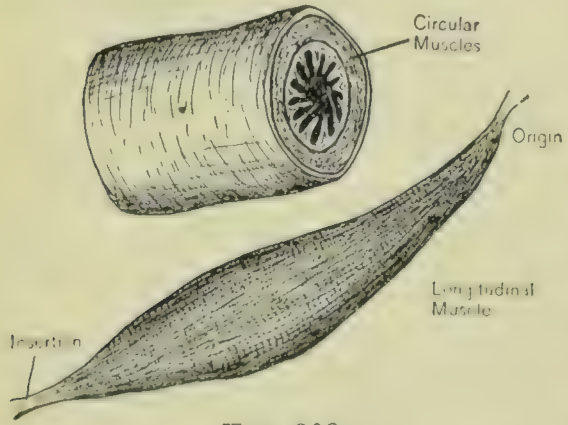


FIG. 308.
Circular and longitudinal muscles.

The method by which food is carried down the esophagus has been partly explained in § 362: the circular muscles contract **above** the food. The esophagus is also provided with **lengthwise** muscles (Fig. 308). These shorten the tube, and pull it over the food, while the circular muscles, by contracting, form a ring behind the food, and push it along.

The stomach has both of these kinds of muscles, and in addition it has **oblique** muscles. As a result of the action of these **three** kinds of muscles, the food received from the esophagus undergoes a **churning** in the stomach. It is thus mixed thoroughly with the **gastric juice,** the secretion of the glands of the stomach.

The gastric juice is chiefly water, but it contains the important ferments **rennin** and **pepsin,** and also hydrochloric acid, in solution. From 5 to 10 pints are secreted daily. Rennin coagulates milk, forming "clots" like those of sour milk. The proteins are insoluble in water, and cannot pass from the alimentary canal into the blood; but the **pepsin** changes them into simpler substances, which are soluble.

The hydrochloric acid of the stomach (§ 246) carries out several important reactions. Thus, pepsin acts best when hydrochloric acid is present. Again, the food coming to the stomach is **alkaline,** from the saliva it contains; the acid **neutralizes** this (§ 249). Since food is exposed to the air before we eat it, it contains a multitude of bacteria. The acid destroys these, and thus prevents infection. We must not, however, depend upon the hydrochloric acid to destroy **all** bacteria, for some, such as those of typhoid, are not killed by it.

The action of the gastric juice changes food to a milky substance called **chyme**; this is ready for digestion in the intestines.

365. The Intestines.— As portions of food are changed to chyme, the muscular ring at the pylorus is relaxed, and the chyme enters the **small intestine.** Both the intestines together form a tube about 27 or 28 feet long. This tube is so long that it must be **coiled** in the abdomen (Fig. 309). Herbivorous animals have even longer intestines; that of the grown ox is about 150 feet long. In man the small intestine is about 22 feet long and 1 inch in diameter; the

large intestine is about 2 inches in diameter. Both of these have lengthwise and circular muscles, like those of the esophagus.

The **intestinal glands** (which secrete the intestinal juice), the **liver**, and the **pancreas** discharge their secretions into the intestines. All of these secretions have an **alkaline** reaction, and thus differ from the gastric juice, which has an **acid** reaction.

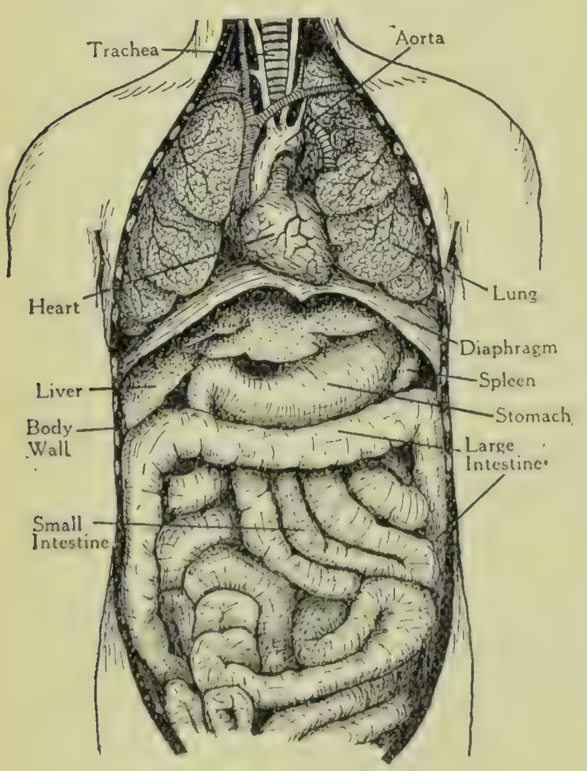


Fig. 309.
The principal organs of the thorax and abdomen.

The organs that are of the greatest importance in **absorbing** the digested food of the small intestine, and in **transferring** nutriment from the alimentary canal to the blood, are the **villi** (singular, *villus*). These are small elevations that project from the wall of the small intestine, and make its absorbing surface about 6 or 7 times as great as if it were smooth. Each villus contains a network of small **blood tubes** (capillaries), and also the **lacteals.** The "food solution," called **chyle,** which the small intestine prepares, goes into the villi, and from these the blood tubes and lacteals absorb it. The lacteals absorb only the digested fats; the blood tubes absorb the other kinds of food.

Between the small intestine and the large one there is a narrow opening which allows food to pass. The large intestine begins at the level of the right hip, passes up the right side to the diaphragm, then across the abdomen to the left side, and down the left side. It does some of the work of absorption, although it has no villi; but its chief use is to discharge the solid waste from the body. It takes about 2 days, under normal conditions, for food to pass the length of both intestines.

The **vermiform appendix,** which when inflamed produces *appendicitis*, is an outpouching in the large intestine, near the place where the small intestine and large intestine unite. It is a small, closed tube, about $\frac{1}{4}$ of an inch in diameter, and about 2 inches long.

366. The Liver and Pancreas.— The **liver** is a dark-red organ weighing about 4 pounds. It is on the right side of the abdomen, under the lower ribs. The liver has several very important functions. For one thing, it helps to remove from the blood the waste nitrogen compounds formed by the destruction of the cells. A **second** function of the liver is to make and to store **glycogen**, a starchlike substance that is readily changed to sugar when the body needs it. A **third** use of the liver is to secrete **bile**, a yellow, bitter liquid, which is emptied by the **bile tube** into the small intestine.

The **bile** is collected from the blood by a multitude of **bile ducts.** A tube leads from the liver to the **gall bladder,** a sac that receives and stores the bile when it is not needed. When the pylorus allows food to pass from the stomach into the small intestine, the bile is poured out for the food's digestion. The bile lubricates the intestine, and helps all the operations of digestion and absorption in the intestine. When bile is not secreted properly, **biliousness,** accompanied by headache and indigestion, is the result.

We have already learned about some of the **ferments** of the digestive tract: the **ptyalin** of the saliva (§ 360) and the **rennin** and **pepsin** of the gastric juice (§ 364). Important as these ferments are, they are not so important as the ferments that are poured into the small intestine in the secretion known as the **pancreatic juice.** Its ferments are:

(1) **Amylopsin,** which completes the digestion of **starchy** foods ("ămylum" means **starch**).

(2) **Steapsin,** which digests **fats** ("stear" means **fat**).

(3) **Trypsin,** which completes the digestion of proteins.

The pancreatic juice is a thin, watery liquid, like saliva. The **pancreas,** which secretes it, is a tongue-shaped gland which lies behind the stomach. The pancreas of the lower animals, such as the pig, is called **sweetbread.** The duct from the pancreas unites with that from the liver, so both the bile and the pancreatic juice enter the small intestine through the same opening.

367. How Digestion Changes Food.— Let us now look at the process of digestion as a whole, and ask: "What is the fundamental thing that digestion in the mouth, stomach, and intestines does?" The answer is that this digestion makes food **soluble**, so that it can go through the wall of the alimentary canal into the blood and lymph. Most of the proteins do not dissolve in water; neither do the fats and starch. How, then, can food be made to dissolve? We have already learned that matter consists of **molecules** (§ 49). While all molecules are extremely small, yet some are very complex as compared with others. The molecules of most food materials are especially complex. To make these food materials dissolve, their molecules must be broken down into **simpler** molecules. This is the work that the ferments, or enzymes, perform in digestion.

What, then, is accomplished in the digestion of **starch?** The final result is the change of the starch into **grape sugar,** which is a soluble substance, and can be taken into the blood stream. What is the digestion of **proteins?** It is the breaking down of these complex materials, by the ferments of the stomach and the small intestine, finally into bodies called **amino acids,** which get into the blood. What, finally, happens to the fats? The steapsin of the pancreatic juice probably breaks their molecules into those of **glycerine** and the **fatty acids,** which, either in solution or in the form of an **emulsion** (§ 253), can be taken through the cell walls of the villi and into the lacteals.

368. Absorption, Metabolism, and Storage.— We are likely to think of **absorption** as merely the transfer of digested food to the blood; but it is more than this. It is partly a **building-up** of the complex substances which were broken down in digestion. Thus the blood does not contain the fatty acids and glycerine obtained by the digestion of the fats, but it does contain fats, built up out of glycerine and acids. We must remember that the complex molecules of our food are not the actual nutrients that the cells can use, although they contain the "pieces" out of which the body's fats and proteids can be built, after digestion.

The **last stage** in the digestive process is called **metabolism** (mĕt-ăb′ōl-ĭsm). This takes place **at the cells.** Here the end-products of protein digestion, brought by the blood and lymph, become a part of the **living protoplasm.** Here also, in some mysterious way, the cell protoplasm causes the sugar and fat and, to some extent, the amino acids, to unite with oxygen (§§ 50 and 299). It is this reaction that sets free the **energy** which the cells must have for their work, and which keeps the body warm.

We eat only at intervals, while the body needs food all the time. Hence there must be ways in which food can be **stored up** during the time of abundance, in order that the body may have a supply to draw upon when its cells wear out, and its energy is low. We have already learned that carbohydrates are stored up by the liver (§ 366) as **glycogen.** The muscles also store glycogen. When the cells take grape sugar from the blood, glycogen is changed to sugar to keep up the blood's supply.

Fat is stored away in the spaces of connective tissue, as under the skin, between the muscles, and among the organs of the abdomen. Fat so stored forms **fat tissue.** Animals that are inactive in winter (**hibernate**) usually store up a large amount of fat to nourish their bodies during their long fasting. The **blubber** of the whale is a thick layer of fat stored under the skin. The camel's **hump** is fatty material that can be drawn upon when the animal has no opportunity for feeding.

369. Alcohol and Its Effects.— The story of the injury alcohol has done to men is a long and sad one, but at present we shall consider only its effect upon the digestion and assimilation of food, and its injury to the digestive organs. When alcohol is poured over proteins, outside of the body, it makes them **coagulate**, or harden, so that they will not decay or ferment. This is a good thing in the preserving of museum specimens, but it is not what we want in the case of a food. For food, as we have learned, is eaten, not that it may be preserved, but that it may be **broken down** by the ferments of the body. A strong drinker suffers from indigestion largely because his food has been hardened and made unfit for the body. Besides injuring the food, alcohol paralyzes the stomach muscles, so that they cannot mix the food thoroughly with the gastric juice.

Those who defend the using of alcohol often tell us that it is a **food.** It is true that a small amount of it can be oxidized at the cells, and that this oxidation gives some energy; but it is also true that the cells are **greatly injured** by it, and that for this reason it cannot properly be called a food, but must be called a **poison.** The only reason for which drinkers insist on calling alcohol a food is that they want an excuse for satisfying the alcohol appetite. Alcohol undergoes no process of digestion. It passes at once from the stomach into the blood and the lymph, and to the cells. But there is too much alcohol for the cells even in the amount taken by a moderate drinker. Now, when real food is digested in an amount that is beyond what the cells need, it can be stored. In this way sugar and fat are stored (§ 368). But alcohol cannot be stored. That which cannot be oxidized at once, and used as a source of energy, becomes simply waste, carrying harm wherever it goes.

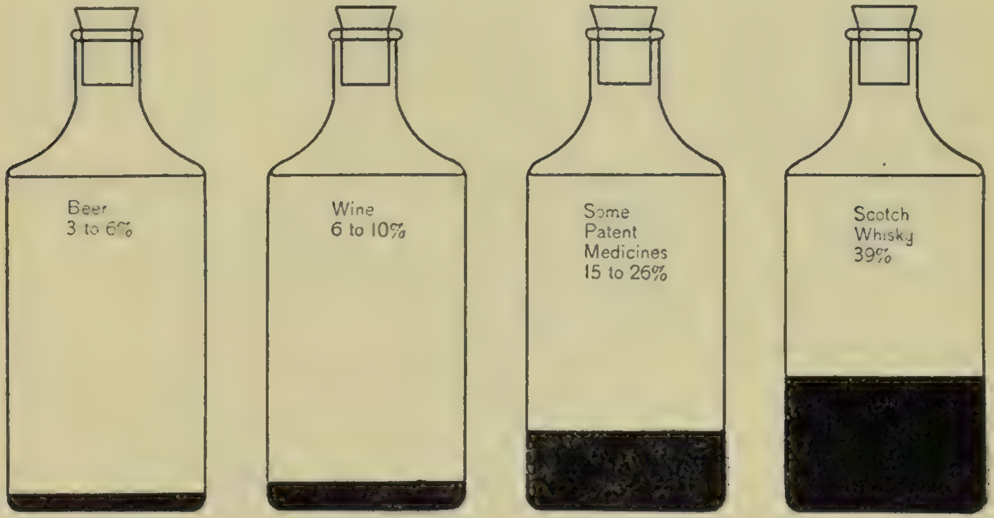


FIG. 310.
Amounts of alcohol present in liquors and in some patent medicines.

Many **patent medicines** contain a great deal of alcohol (Fig. 310), and people take them without realizing this fact. A medicine containing alcohol will produce all the effects of alcoholic liquors, and will develop an alcohol appetite in persons who would not think of becoming drinkers. Patent medicines may also contain injurious **drugs,** such as opium and chloral. An illustration is the "soothing syrup" that is often given to young children. People ought to know that when they are giving a "paregoric" soothing syrup, they are giving a preparation of **opium,** and that the child becomes quiet, not because it is cured, but because it is stupefied. The after-effects of such drugs are often very injurious. No medicine of this sort should be taken or given unless a competent physician prescribes it.

370. Summary.— Man is a **vertebrate.** His body has a **dorsal** and a **ventral cavity.** The dorsal cavity contains the **brain** and **spinal cord.** The ventral cavity consists of the **thorax** and **abdomen.**

Physiology is the science that has to do with the organs of animals and plants, and with the functions of the organs.

The body is composed of **living cells.** A group of cells, all of which do the same kind of work, is called a **tissue.**

Bones are made chiefly of connective tissue stiffened with limestone and calcium phosphate. **Cartilage** is a type of connective tissue.

Joints are places where bones come together.

At **movable** joints bones are held together by **ligaments.** Movable joints may be **hinge, ball-and-socket,** or **gliding** joints.

The **skeleton** consists of 206 bones.

Muscles are structures that move the body. They are made of **muscle tissue** and **connective tissue.**

Tendons are extensions of the connective tissue of muscles.

The bones act as **levers,** muscles being the "**power.**"

Muscles are **voluntary** or **involuntary.**

When bones of a joint are separated, the joint is "dislocated." In a "sprain" the bones remain together, but the ligaments are injured.

The tube in which digestion occurs is the **alimentary canal,** or **digestive tract.** Digestion is carried out by liquids taken from the blood (secreted) by organs called **glands.**

The **mouth** contains **salivary glands,** which secrete **saliva.** Saliva contains a ferment or enzyme, **ptyalin.**

The **teeth** crush the food, and mix it with the saliva.

Food is **swallowed** by the action of the muscles of the **tongue, pharynx,** and **esophagus.**

Food enters the **stomach** from the esophagus, and leaves it at the **pylorus** opening, entering the small intestine.

Gastric juice contains the ferments **rennin** and **pepsin,** and **hydrochloric acid.** Pepsin begins the digestion of proteins.

Digestion in the **small intestine** is carried out by 3 types of secretions. The intestinal glands secrete the **intestinal juice.** The **liver** secretes the **bile.** The **pancreas** secretes the **pancreatic** juice.

The **pancreatic juice** contains the ferments **amylopsin, steapsin,** and

trypsin; these complete the digestion of carbohydrates, fats, and proteins, respectively.

Absorption in the small intestine takes place through the **villi;** these contain blood tubes and **lacteals.**

The **object of digestion** is (1) to get the food into **soluble** form, and (2) to get the large molecules of food substances into smaller molecules that can recombine to form the molecules actually needed by the cells.

The **last stage** of digestion is **metabolism.**

Alcohol coagulates the proteins, and makes their digestion hard; it therefore brings on **indigestion.** It is a **poison,** not a food.

Many **patent medicines** contain alcohol, and are as dangerous as alcoholic liquors.

371. Exercises.— 1. What happens to milk when it enters the stomach? Why? What ferment is used to produce the dessert, junket?

2. Name an easily digested fatty food.

3. Trace the course of meat through the alimentary canal until it reaches the cells, naming the organs it passes through, and the change each brings about.

4. Cases have been known in which surgeons have removed a patient's stomach, and attached the small intestine directly to the esophagus. Could a person without a stomach digest all kinds of food? What would be the chief disadvantage?

5. What changes occur in the absorption of food?

6. Name all the functions of the liver given in this chapter.

7. Show that the energy of our bodies comes from the sun.

8. In what part of the digestive tract are fats digested? What ferment digests them? What ferments digest potatoes? Meat?

9. Why do we "raise" bread? How? Why is bread "heavy," or "soggy"? What is the objection to our eating soggy bread?

10. Suggest a reason why "toasted" bread is so healthful. Why are baked potatoes healthful? Why is a soft-boiled egg more digestible than a hard-boiled one?

11. Why cannot alcohol be called a food?

372. Projects.— 1. Prepare the skeleton of a chicken, mount it, and present it to the school.

2. Bring to class clean bones showing hinge and ball-and-socket joints.

3. Show the class a lengthwise and a cross section of a beef bone.

4. With junket tablets, or some rennet from a calf's stomach, show the coagulation of milk to the class.

5. Get a piece of tripe, and show the class how a large surface is given to the digestive tract.

6. Get some pancreas secretion, or prepare some artificial pancreatic juice, and with it show the class how a fat, such as olive oil, is emulsified when shaken up with water containing the secretion.

7. Use the pancreatic ferments to digest some hard-boiled egg (grated) and some baked potato. Mix each food with a little water, and carry out the experiment at body temperature.

8. Show how alcohol (denatured) coagulates white of egg.

9. Prepare a paper on the dangers from the use of alcohol.

10. Prepare a paper on the dangers in patent medicines.

11. Consult a dentist for information regarding decaying teeth, and present a report on the subject.

12. With the help of a physician prepare a report on the common causes of indigestion and how to avoid it.

373. References.— GULICK: *Hygiene Series.* HOUGH AND SEDGWICK: *The Human Mechanism.* RITCHIE: *Sanitation and Physiology.*

CHAPTER XXI

CIRCULATION AND RESPIRATION

374. The Circulation of the Blood.— Just as the work of Newton is the foundation of modern physics, and as Lavoisier's explanation of burning was the beginning of modern chemistry, so Harvey's discovery (about 1616) that the blood circulates through the body was the starting point of modern physiology. The blood has several very important functions. The **food** that is digested in the alimentary canal must be carried to the individual cells all over the body (§ 368); the blood carries it. The **oxygen** that is taken into the body at the lungs must also be taken to the cells; the blood has the power of carrying oxygen. The cells in the exposed parts of the body (those near the skin, for example) must be kept warm, so that the protoplasm can continue its work; hence the blood is a carrier of **heat,** and keeps up the body's temperature. The reaction between the food and oxygen, which takes place at the cells, gives energy, but it also produces **waste materials** (§ 366). These must not accumulate, or they will poison the body. Hence the blood serves as the great **sewer** into which the wastes of the cells are discharged.

A system carrying liquids through the body needs a pump, or **heart.** The other **organs of circulation** are the **arteries, veins,** and **capillaries.** There are also spaces between the blood tubes and the cells; these are filled with **lymph,** a liquid much like the blood (§ 379).

375. The Heart.—The heart (Fig. 311) lies in the cavity of the thorax, almost surrounded by the lungs. The smaller end is to the **left** of the breast bone, but the larger end is directly behind it. The heart of a person is about as large as his fist. The heart proper is surrounded by a protective covering with a double wall. This is the **pericardium,** meaning "around the heart." Between the two halves of the pericardium there is a liquid that decreases the friction of the heart.

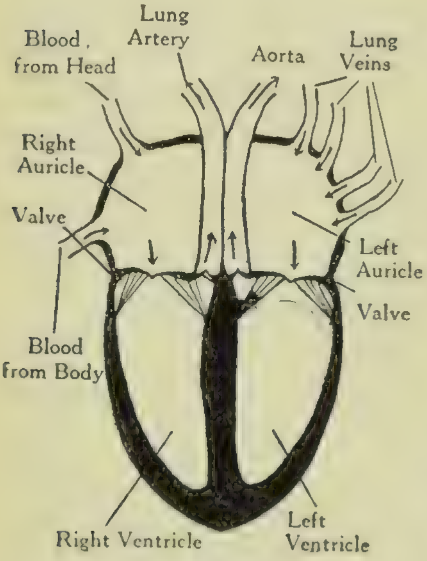


FIG. 311.
The heart and its four chambers. Note the veins, which bring blood to the heart, also the valves and the means of holding them shut.

The heart of man, like that of all mammals, consists of **4** cavities, or **chambers.** These chambers are all needed, because the blood goes through **2** distinct circuits, or "round trips." One of these circuits is from the heart to the body, and then back to the heart. This is the **system,** or **body, circulation.** The other circuit is from the heart to the lungs, and back again to the heart. This is the **lung,** or **pulmonary, circulation.** The two **upper** cavities of the heart are the **right auricle** and the **left auricle.** The auricles **receive** blood **from** the body and lungs. The heart's two **lower** chambers are the right and left **ventricles.** The auricles force the blood into the ventricles; then the ventricles exert the pressure that **drives** the blood **to** the body and lungs. The ventricles have much thicker walls than the auricles, because they have so much harder work to do; and the left ventricle, which forces the blood through the body circulation, has walls much thicker than the right ventricle, which sends the blood through the lungs.

The heart has **4 valves** which permit its outlets to be opened and closed. The valves are made of tough connective tissue, and are strengthened by cords fastening them to the walls of the heart. Blood pressing on one side of the valves makes them open, but when the pressure is on the other side, they come together, and prevent the blood from flowing backward. We are accustomed to think of the heart as a pump; we must rather think of it as **4 pumps.** Two valves permit the blood to pass from the auricles into the ventricles, and two more guard the openings to the two great arteries that carry the blood to the lungs and body. The heart of a child in its first year beats about 120 times each minute. In the fourteenth year the number is about 85; in the adult, about 70 or 80.

376. Arteries and Veins.—The tubes that carry blood **from** the heart are called **arteries;** those bringing blood **to** the heart are **veins.** The artery that carries blood from the left ventricle is called the **aorta;** this artery and its branches supply the **body circulation.** The **pulmonary artery,** coming from the right ventricle, takes blood to the lungs.

Arteries are made of 3 layers of tissue; the middle one contains muscular fibers. Thus, while the arteries are very strong, they are **elastic.** They expand as the blood stream increases in size, and contract as it decreases. Where arteries come near the surface of the body, the wave of blood sent out at each contraction of the left ventricle can be felt as the **pulse.** The pulse reading is usually taken at the wrist. Since the arteries are elastic, they act as extensions of the ventricles, keeping the blood under pressure even when the ventricles are not contracted. They can do this because of the heart valves, which prevent a flow of the blood backward into the ventricles.

Veins have thinner walls than arteries, and are much less elastic. Blood from the body circulation enters the right auricle through several large veins; other veins bring blood from the lungs to the left auricle. Blood enters the auricles "by suction" (§ 14), much as lemonade enters a straw when you remove the air. When the auricle contracts, it forces its blood into a ventricle. When the auricle is relaxed, its cavity increases in volume, and the pressure in the cavity decreases. Blood cannot flow back into the auricle from the ventricle, because the heart's valves prevent this. So the pressure of the blood in the veins, while feeble, is sufficient to force blood from the veins into the auricles. The body has ways of helping the feeble blood pressure in the veins. Many veins are so placed that they are easily compressed by the body muscles that are near them. Muscles in active use can thus hasten the flow of blood in the veins. Veins of this sort have valves opening **toward** the heart, but not away from the heart. Nature takes care to have the blood go in the right direction.

377. Capillaries.—The capillaries are the smallest of the blood vessels (§ 119), with an average diameter of about $\frac{1}{2000}$ of an inch. While the purpose of the blood's circulation is to get food and oxygen **to** the cells, and to remove waste materials **from** the cells, yet the walls of arteries and veins are too thick to permit the passage of blood materials. It is only in the capillaries that the walls are thin enough.

The capillaries extend to all parts of the body. They are in all **glands** (§ 359), for it is through the capillaries that glands get the juices which they secrete; they are near the **digestive organs,** to take the digested food into the blood (§ 365); they are in the **lungs,** to permit the blood to give off its waste carbon dioxide, and to take in oxygen. Capillaries may be looked upon as the tiniest branches of the arteries, carrying blood to the body; they are also the small beginnings of the veins, in which the blood is gathered for transportation back to the heart. We can compare the flow of blood through arteries, veins, and capillaries with the flow of a stream of water through a bed of sand. The channel that brings the water is like an artery; the channel through which it flows after passing through the sand is like a vein; the thousands of tiny channels, by which the water finds its way through the sand, correspond to the capillaries.

378. The Blood.—The blood consists of **two** parts. One is a colorless liquid called the **plasma;** the other is a multitude of tiny bodies called **corpuscles.** The plasma is made up of water and of dissolved materials. Among the dissolved materials are the amino acids, made out of digested proteins (§ 367). There are also fats, salt, and grape sugar. Besides the foods and minerals, the plasma contains waste substances, chiefly carbon dioxide and urea.

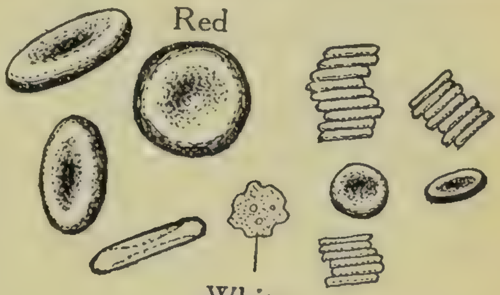


FIG. 312.
Corpuscles, greatly magnified. The white ones are really larger than the red.

The **corpuscles** (Fig. 312) are of **2** kinds: **red,** and **white.** The red corpuscles are much more numerous than the white ones, but smaller. As seen under the microscope, a red corpuscle is a thin, yellow cell (**not** red), disclike in shape. The red corpuscles are generally in groups, like "stacks" of coins. The groups appear red. Red corpuscles contain protoplasm and a dark-red substance called **hemoglobin** (from *haima,* "blood," and *globe*). Hemoglobin forms a bright-red compound with oxygen; this is **oxyhemoglobin.** It is as a part of this compound that oxygen is carried from the lungs to the cells. Bright-red blood is, therefore, blood with a good supply of oxygen; dark-red blood is poor in oxygen.

White corpuscles are also single cells. Like amebas, they have the power of changing their shapes and of moving about. They can pass through the walls of capillaries into the **lymph** (§ 379). White corpuscles destroy disease germs that get between the cells, also the germs in the blood. When you receive a wound that penetrates the skin, they form a protecting wall around the wound, and usually keep germs from reaching the remainder of the body.

When a wound bleeds, it is because a blood vessel has been cut (Fig. 313). The blood at once seeks to close the opening by forming a thick mass, called a **clot.** The clotting, or **coagulating,** material is **fibrin**; it is formed out of **fibrinogen,** one of the proteins of the blood. This substance coagulates, even at the blood's temperature, much as the white of egg coagulates when heated. If a little absorbent cotton is placed on a wound, its fibers help the fibrin, and the blood is coagulated more quickly.

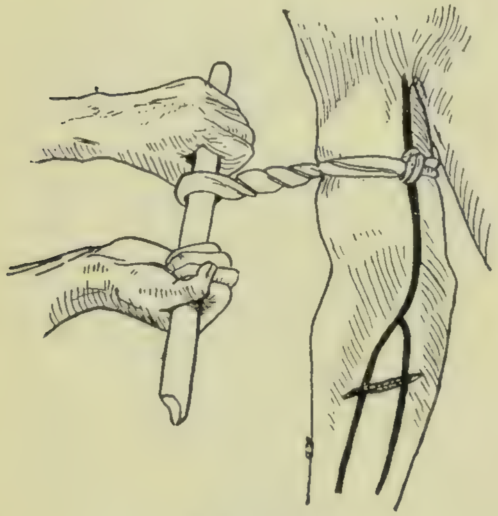


FIG. 313.
A tourniquet. The handkerchief is tied loosely around the arm, and a stick is used to twist the loose loop, so that the knot presses against the cut blood vessel.

379. The Lymph. — The lymph is really another form of the blood. It is made out of the plasma and white corpuscles of the blood, which pass through the capillary walls, and out of water and waste materials from the cells. The lymph fills the spaces between the cells. We have learned (§ 377) that the capillaries give oxygen and food materials to the cells, and that the cells give waste materials to the blood. This is not strictly true; the capillaries give their materials to the lymph, and the cells really get their food supply from the lymph. In the same way the cells discharge their waste into the lymph, and the lymph passes it on to the capillaries. Thus the capillaries and the cells really exchange material through the lymph that is between them.

In the human, the lymph has no special pumping organ. For its movement it depends upon the pressure of certain organs such as muscles. In this respect the movement of lymph is like the movement of blood in certain veins (§ 376). The lymph is gradually collected into two large tubes, called **lymphatic ducts.** By these it is discharged into the blood. The lymph of the higher animals resembles, in many ways, the colorless blood of the lower animals, such as insects. In each case the absence of a pumping organ and of definite tubes makes the circulation slow.

380. Excretion.— As we have already learned (§ 359), glands **secrete** liquids from the blood. If the secretion is waste that needs to be expelled from the body, it is called an **excretion.** Excretion is just as necessary as any body function, for the wastes are poisons to the body. The most important wastes to be removed, aside from the solid waste of the alimentary canal, are water, carbon dioxide, uric acid, urea, and certain salts. The carbon dioxide is removed chiefly by the lungs. Most of the other materials are in solution, and are removed by the **kidneys.** There are **2** kidneys; they are attached at the back of the abdomen, one on each side of the backbone. They have the shape of beans, and weigh about 5 ounces each. The kidneys receive a large supply of blood from the heart. After removing the waste, they return the purified blood to the body. The solution collected by the kidneys is passed on to the **bladder,** where it is stored until it is expelled from the body. Alcohol drinkers are especially liable to dangerous diseases of the kidneys (§ 369); **Bright's disease** is one of them.

381. Respiration.—The need of respiration has already been given, and respiration has been defined (§ 71). We need to respire: (1) to bring oxygen **to** the blood; (2) to remove carbon dioxide **from** the blood. The circulation of the blood brings about oxidation at the cells, and also carries the carbon dioxide to the lungs. The oxidation at the cells is **internal** respiration. The exchange of gases between the air and the lungs is **external** respiration, or **breathing.** The chief organs of external respiration are the **lungs,** and the **air passages** which connect the lungs with the air. To these we must add the muscles and bones of the chest, which aid in breathing.

382. The Lungs.—The lungs (Fig. 314) are two spongy organs that hang in the thorax, and are surrounded by two sacs of connective tissue. The sacs are called **pleurae** (singular, *pleura*). The heart cavity is between them. The lungs are the meeting place of air and blood; hence we find them to be a mass of air passages and air cells on the one hand, and of blood vessels on the other. Connective tissue holds these together. The lungs are lined with mucous membrane, just as the other air passages are (§ 359). The entrance of air into the lungs, and its passage out of the lungs, depend upon the expansion and compression of the lungs; hence the lungs are not rigid, but elastic. The air sacs of the lungs number many millions. Their surface in an adult has been estimated to be over 2,000 square feet. This is the floor area of a room 20 feet wide and 100 feet long.

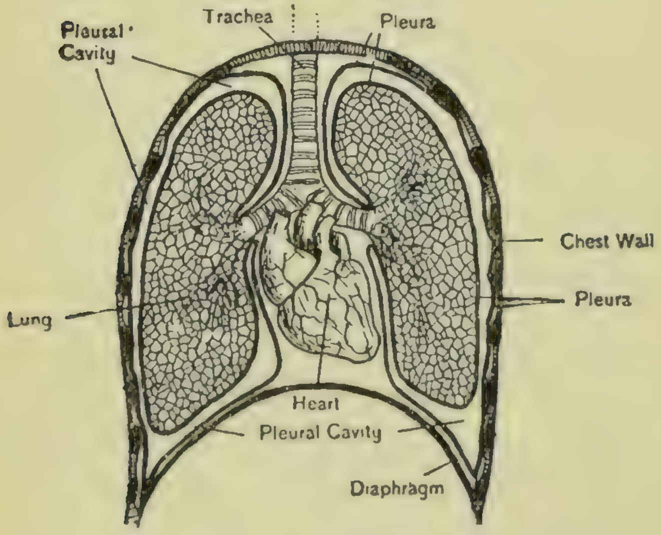


FIG. 314.
The lungs and their surroundings, including the diaphragm.

A large artery (the **pulmonary** artery) carries dark-red blood from the heart's right ventricle to the lungs. This blood is spread out through the network of capillaries that is in the air sacs, and loses its carbon dioxide. At the same time it takes up oxygen, and becomes bright red. Then it is carried, by the pulmonary veins, to the heart's left auricle. This pumps it into the left ventricle, by which it is forced, through the aorta, to the body.

The air that enters the lungs contains 21% oxygen, 78% nitrogen, and 1% argon. As it leaves the lungs, it contains about 16% oxygen and nearly 5% of carbon dioxide, water vapor, and other impurities. The loss of oxygen is thus balanced by the gain in carbon dioxide. The amounts of nitrogen and argon are not changed. About 1.2 pounds of water and 1.5 pounds of carbon dioxide are exhaled from the lungs daily. As the air exhaled is warm, and as the water is in the form of vapor, the lungs aid the skin in removing heat from the body (§ 388).

383. Inspiration and Expiration.— The external respiration (breathing) consists of: (1) **inspiration,** or "breathing in"; and (2) **expiration,** or "breathing out." The entrance of air into the lungs (inspiration) is brought about by the **enlarging** of the chest (§ 79).

The expansion of the chest is brought about in two ways. One of them is the *contraction* of the *diaphragm,* the muscular partition that separates the thorax from the abdomen. When the diaphragm contracts, it pushes the organs of the abdomen downward, and makes the thorax larger. This permits the outer air to rush into the lungs. The second means by which the expansion of the chest is brought about is by the action of the chest muscles. When the diaphragm moves **downward,** these muscles pull the breastbone and ribs **outward.**

The air taken into the lungs during inspiration is expelled when the muscles of the chest and diaphragm are relaxed. The ribs move downward and inward of their own weight, and the organs of the abdomen, which were crowded together during inspiration, expand again, and force the diaphragm up against the lungs. As a result, the elastic air cells of the lungs, which were "puffed out" with air, are now compressed and the air is forced back through the air passages. The air that we inhale and exhale during ordinary quiet breathing is called **tidal air.** It is about a pint (30 cubic inches, or 500 c.c.). By making a conscious effort we can take in and expel about 100 cubic inches more air than in quiet breathing. The total capacity of the lung is about **1.5 gallons** (331 cubic inches; 5.7 liters). An adult "breathes," on the average, 18 times in a minute.

384. Exercises.— 1. Trace tne course of a drop of blood from the time it leaves the left ventricle until it re-enters it.

2. Is the heart a suction pump or a force pump? Why has the left ventricle stronger muscles than the other heart chambers?

3. Why does the doctor "take your pulse" when you are ill? Why does he take your temperature?

4. What is meant by the "transfusion" of blood?

5. Why is the blood in the veins "blue blood"? How, in an accident, can you tell that you have cut an artery rather than a vein? Which would be the more serious, and why? On which side of a wound ought an artery to be compressed, so as to stop bleeding, on the side toward the heart, or away from the heart? How, in the case of a cut vein?

6. Draw a sketch showing the cells of a capillary wall (a single layer, end to end), and show how an ameba-like cell, such as a white corpuscle, might get out.

7. What is the special duty of red corpuscles? Of the white ones? What body fluid forms the "matter" of a blister?

8. If you were on a high mountain top, would there be as much oxygen in every breath as at sea level? How can the body increase the oxidation of the blood at high altitudes?

9. When does the heart have more work to do, when we stand, or when we lie down? Why?

10. Do you think continued and violent physical exercise would have any effect on the size of the heart? Why?

11. When a boy or girl grows very rapidly, how is the heart's work affected? Ought violent exercise to be indulged in at this time?

12. Why are you "out of breath" after running?

13. How does very dry air affect the organs of respiration?

14. Give the course of air in going from the nostrils into the lungs. Give the course of the oxygen from the lungs, through the body circulation, and back again to the lungs.

385. The Nose and Throat.—The air that enters the lungs goes through several passages (Fig. 307): the **nasal passages,** or nostrils, the **pharynx,** or throat, the **larynx,** the **trachea,** or windpipe, and the **bronchial tubes.** All of these are lined with mucous membrane. In the **nostrils** the mucous membrane is spread out over a large surface, and secretes a great deal of mucus. The nostrils, because of their length, serve to warm the air before it reaches the windpipe and lungs. The mucus which they secrete makes them moist, and catches the dust particles that are in the inhaled air. The air passages are also lined, almost everywhere, with delicate **cilia**; these sweep back the dust particles.

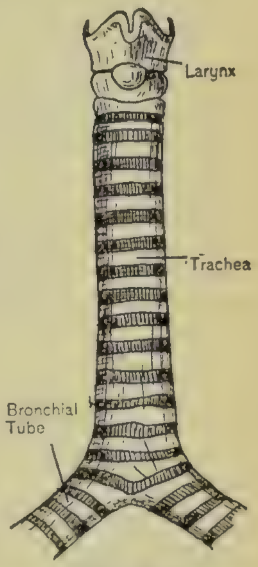


FIG. 315. The larynx, trachea, and bronchial tubes.

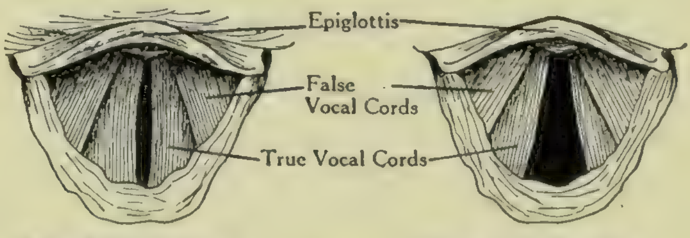
The **pharynx** (§ 362) is separated from the nostrils, when we swallow food, by the "soft palate." The two **tonsils** are in the sides of the pharynx, under the lower jaw bone.

The larynx (Fig. 315) is a box made out of pieces of cartilage placed at the upper end of the trachea (windpipe). When we swallow, the larynx is drawn upward against its cover, the **epiglottis** (Fig. 307); food passes **over** it in going to the esophagus. We can feel one of the larynx cartilages (the "Adam's apple") at the front of the throat. During breathing, the larynx drops down, and there is free communication between the nasal passages and the trachea.

The **trachea** is a rounded tube about an inch in diameter. It holds its shape because of a number of pieces of cartilage; these are bent in the shape of a **C**. The trachea divides into two passages, or **bronchi,** one of which goes to each lung. The bronchi divide and subdivide into the **bronchial tubes.** The smallest of these end in the air cells of the lungs.

386. The Voice.—The larynx not only forms the opening from the throat to the trachea, but it also holds the chief organs of the voice, the **vocal cords** (Fig. 316). The vocal cords are two strips of connective tissue fastened to the cartilages of the larynx. When not in use they are drawn aside, leaving a V-shaped opening. The cords are brought into use by means of muscles. These act on the cartilages of the larynx, and bring the edges of the cords near each other. The air that passes through the larynx makes the cords **vibrate,** producing sounds. The sounds are soft or loud according to the amount of air used.

The **pitch** of the voice (§ 223) depends chiefly upon the degree of tightness of the vocal cords, and upon their length. When the cords are tightly drawn, and short, they vibrate more rapidly than when loose and long; hence they produce sounds of higher pitch. A man has a larger larynx than a woman has, and his vocal cords are larger and longer. As a result his voice is of lower pitch.



When Producing Sound During Quiet Breathing

FIG. 316.
The vocal cords in two positions.

We use the vocal cords in ordinary **speaking** and singing, yet we can "whisper" words without using the vocal cords at all. We make the whispered words with the throat, tongue, teeth, and lips. When we want to give loudness and pitch to our words, we force the necessary amount of air over the vocal cords. The throat, mouth, and nostrils also strengthen the sounds that come from the vocal cords. The **quality** of a voice is that peculiarity which distinguishes one voice from another. By means of it we recognize the voices of our friends. Voice quality depends on the special shape of the air passages and mouth in each person, and on the peculiar way in which each of us uses them in speaking and singing.

Vowels, or "vocals" (**a, e, i, o, u,** and **y**) are the vocal-cord sounds that are changed least by the other organs of speech; **consonants** are greatly altered forms of these sounds.

387. Care of the Respiratory Organs.— In our breathing, as in eating and drinking, we are taking external material into the body. If there are disease germs in this material, they have opportunity to develop and to cause disease. We therefore need to guard against throat and lung diseases, as well as against typhoid. The surest way to keep the organs of respiration in good health is to learn **good methods** of breathing, and to breathe **good air** (review Chap. VI).

Colds require the greatest care, for they lower the power of the body, especially of the organs of respiration, to resist disease, and make these organs fall an easy prey to pneumonia, tuberculosis, and diphtheria. The practice of deep breathing is a great aid in preventing colds.

Tobacco smoke irritates the throat and lungs by clogging up their delicate membranes with soot. **Cigarettes,** especially, are harmful to the organs of respiration. Their smoke contains not only the poison of tobacco (nicotine), and poisonous gases like **carbon monoxide,** but also very irritating organic compounds called **aldehydes,** which bring on the "hacking" cough of the cigarette user.

Alcoholic liquors are likely to bring on weakness of the lungs, so that the drinker is easily attacked by pneumonia and consumption.

Tight clothing is a serious hindrance to good breathing. If clothing is too tight about the chest, the chest cannot be enlarged properly in inspiration. If it is too tight at the waist, it compresses the diaphragm, the ribs and the organs of the abdomen, and makes full breathing impossible.

388. The Skin.—The skin (Fig. 317) serves as an outside covering for the body, protecting it from hurts, and from the germs of disease that are constantly in the air. It consists of: (1) the **true skin,** or **dermis**; (2) the **outer skin,** or **cuticle.** The cuticle is also called the **epidermis,** meaning, "upon the dermis" (§ 314).

The **epidermis** consists of transparent cells, and has no nerves or blood vessels. It forms a tough, outside covering. The lower layer of epidermis cells is in contact with lymph, and from it gets the nutriment that is needed for the making of new cells. These take the place of those rubbed off at the surface. Where the skin is put to rough use, as in the palms of the hands and the soles of the feet, the epidermis becomes thick, forming a **callus.** A **corn** is a thick layer of epidermis cells formed at one spot. It hurts because it is pressed, by the shoe, into the true skin beneath.

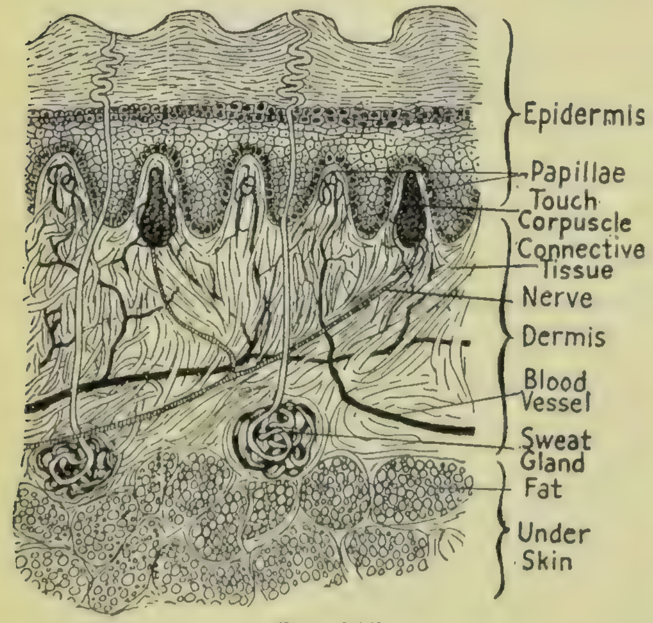


FIG. 317.
Note the three layers of the skin, especially the complex dermis, or true skin.

The **dermis,** or true skin, is much thicker than the epidermis. It is made up of tough fibers of connective tissue, and has blood vessels and nerves. The surface of the dermis has little elevations called **papillae,** some of which contain the bodies that bring about the senses of touch and of temperature (§ 406). On the inner side of the hands and fingers the papillae are arranged in rows. No two persons seem to have exactly the same arrangement of papillae, hence persons may be identified by their **finger prints.** A **layer of fat** is generally found under the dermis.

The **color** of the skin is due to coloring matter in the lower layers of epidermis cells. When the skin is **tanned** by wind and sun, the coloring matter is increased. **Freckles** are spots of coloring matter in the epidermis.

389. The Perspiration.— The perspiration is the liquid poured out upon the skin by the **sweat glands** (Fig. 317). These glands are tubes coiled at their lower ends, and set into the lower part of the dermis. Their purpose is to cool the body (§ 54). It is only when we are very hot that the sweat collects on the skin in drops (**sensible perspiration**). The sweat glands are under the control of the **nervous system**; much or little perspiration is given off, according as the body needs to give off heat, or to retain it.

390. The Hair and Nails.— The hair and nails (Fig. 318) are made of cells of the epidermis, but they have taken **special forms.** A **hair** is a tiny **tube,** formed in a pocket of the dermis. The part projecting from the skin, like the epidermis itself, has neither blood vessels nor nerves. But the inner end of the hair is in the true skin, and is kept growing by the formation of new cells. These are nourished by the lymph of the dermis. Tiny muscles in the hair "pits" sometimes cause the hair to "stand on end," causing "goose-flesh." The hair covers nearly the whole body.

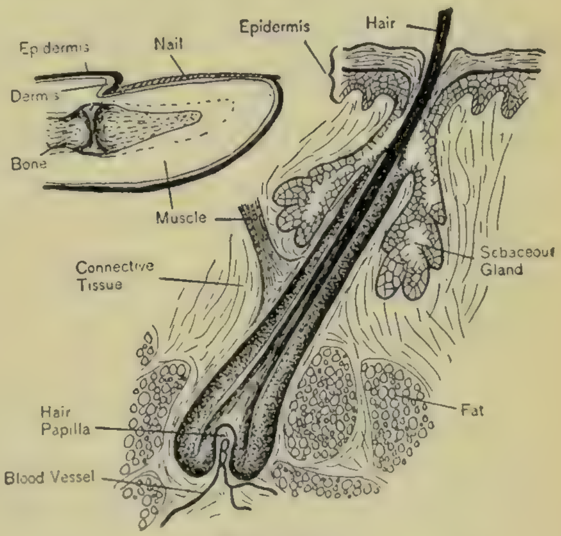


FIG. 318.
Structure of the nails and hair.

In the hair pits there are glands that secrete an oil for the hair; these are the **oil glands,** or **sebaceous** glands. The oil softens the skin and the hair. Brushing the hair helps the oil glands in their work, for it spreads the oil along the outside of the hair.

Dandruff in excess is generally considered a disease. It is probably due to bacteria, and may spread from one person to another. Only **clean** combs and brushes should ever be used for the hair. If we pull a hair out without destroying the cell that produces it, a new hair will grow. In **baldness** the cells lose the power of producing new hair. The cause of all baldness is not known, but much of it seems to result from dandruff, or from a lack of fat in the scalp.

The **nails** are plates of tough epidermis that grow out of depressions in the dermis. They grow in length and thickness as new epidermis cells are formed at their inner ends, or **roots.** The older part of a nail is **transparent**; the blood vessels beneath it make it appear pink.

391. Work of the Skin.— Some of the functions of the skin have already been given. It is, first of all, a **covering** for the body; it also contains the structures that act upon the **nerves of touch.** In giving off perspiration it is an organ of **excretion,** like the kidneys (§ 380). It is likewise one of the **regulators** of the body's temperature; the skin and the lungs together enable the body to cast off the heat it does not need.

The body remains at the normal temperature (98.6° F.) whether we exercise or remain at rest, when the weather is cold as well as when it is hot. This temperature therefore represents a condition of **balance** in the body's heat supply; at 98.6° F. we gain heat and lose heat in equal amounts. When we are warm, the blood rushes to the surface of the body. The skin then **radiates** heat rapidly; a rapid flow of **perspiration** also takes place. By these means the blood is cooled, and the body's heat is lowered.

If the heat of the body needs to be saved, as when we are in a cool room, the blood vessels near the surface grow smaller, and less blood comes to the skin. Thus the body loses less heat. If the lack of blood near the skin continues for a time, we feel **cold.** Then, if we are wise, we raise the temperature of the room, or wear warmer clothing.

The need of **bathing** has already been given (§ 251). The skin becomes covered with **body wastes** from the evaporated perspiration, with **oil** from the sebaceous glands, with **dust** from the clothing and the air, and with dead **epidermis.** The best kind of a bath for removing this accumulation is a **warm** bath; it should be taken at night, if possible. Warm baths taken in the daytime, unless they are followed by a cold shower bath, or by a dash of cold water, may make one liable to colds (§ 387). A warm bath at night also aids in bringing on a good night's sleep.

In the morning, when we wish to be aroused for the day's work, especially if we must go out into the cold, a **cold** bath is the best. The cold water gives the body a **shock,** in which the blood is driven inward from the skin; but after a vigorous rubbing the skin **glows.** This is due to the "reaction," as the blood re-enters the skin.

Many persons cannot endure the shock of a tub of cold water; they do not have a proper reaction, and feel chilly. Such persons can, as a rule, take a cold "sponge" bath, in which the water is applied rapidly with a wet sponge or washcloth. Vigorous rubbing with a dry, rough towel will bring about the "reaction."

392. Summary.— The **blood** carries oxygen and digested food to the cells, distributes the body's heat, and acts as the sewer for cell wastes.

The **organs of circulation** are the heart, arteries, veins, and capillaries; also the spaces containing the lymph.

The heart has 4 chambers: 2 **auricles** and 2 **ventricles.**

The **right auricle** receives blood from the **body circulation,** and forces it into the **right ventricle.** This, in its turn, forces the blood to the lungs to be oxidized.

The **left auricle** receives purified blood from the lungs, and forces it into the **left ventricle.** This forces it, through the artery called the **aorta,** into the body circulation.

The **valves** of the heart make the blood flow in **one** direction.

Arteries carry blood **from** the heart; **veins** carry it **to** the heart; **capillaries** carry it from arteries to veins **through** the tissues.

The **blood** consists of the **plasma** and **corpuscles.** Corpuscles are **red,** and **white.** Red corpuscles contain **hemoglobin,** which combines with **oxygen** at the lungs. White corpuscles have the power of independent motion; they destroy bacteria.

The coagulated material of a blood clot, which closes a wound, is **fibrin,** formed out of one of the proteins of the blood.

Lymph is a form of blood that exists outside of the organs of rapid circulation. It has no red corpuscles. The capillaries give their food material to the lymph, and this gives it to the cells.

Excretion is the removal of **waste** products. The chief excreting organs are the **kidneys.** The **skin** excretes waste in the perspiration.

Respiration brings oxygen **to** the blood, and removes carbon dioxide.

The chief **organs** of respiration are the two lungs and the air passages. The **pleurae** are sacs that surround the lungs.

In the lungs the air loses about $\frac{1}{4}$ of its oxygen, and takes up carbon dioxide in its place.

In **inspiration** the chest is enlarged, and the outside air rushes into the lungs. In **expiration** the diaphragm and ribs are crowded against the lung cavity, and force out the air.

The **air passages** include the nasal passages, the pharynx, the larynx, the trachea, and the bronchial tubes.

The **larynx** contains the vocal cords. In speaking and singing we use the throat, tongue, lips, teeth, and nostrils, as well as the vocal cords.

We should have **good** habits of **breathing.**

Colds, tobacco, alcohol, and **tight clothing** are all sources of danger to the organs of respiration.

The **skin** consists of **epidermis** and **dermis.**

Perspiration is secreted by the sweat glands of the dermis.

Hair and **nails** are special forms of epidermis; they grow from pits ("roots") in the dermis.

The **functions** of the skin are to cover the body, to assist in touch, to excrete perspiration, and to help regulate the body's temperature.

Bathing restores to the skin a fresh, clean surface, so that it can carry out its functions.

393. Exercises.— 1. With what organs of speech do you make the sounds of *k*, *l*, *g*, *d*, *t*, *m*, *s*, and *f?* Find out how you make the sounds of all the letters of the alphabet, and make a list of them, putting together all the letters that seem more or less alike.

2. If you feel chilly, a few deep breaths, especially if you "hold your breath" while the lungs are full, will make you warm. Tell why.

3. Why should one go to bed when he has a bad cold?

4. What harm is done by the wearing of tight belts?

5. What is the danger in taking a hot bath, and then going out into the cold air? How may the danger be made less?

6. What are the uses of the finger nails?

7. How does a dog cool his body when he is hot?

8. Alcohol drives the blood into the skin, giving a temporary feeling of warmth. Is a drinker wise in "fortifying" himself with liquor before going out into the cold?

394. Projects.— 1. Study, and then demonstrate to the class, the method of restoring breathing in a drowned person.

2. Study, and then show the class, the method of stopping nosebleed.

3. Demonstrate the use of a tourniquet (Fig. 313).

4. Have a student in biology help you to prepare a sterilized gelatine plate, and show the class the development of bacteria from the dust of a school hall.

5. Devise apparatus to demonstrate the action of the lungs in inspiration and expiration.

6. Prepare a finger-print record of each person in the class. With a roller, if possible, put a very thin film of printer's ink upon a glass plate, and then **roll** each finger of the right hand, beginning with the thumb, first in the ink film on the plate, and then on a clean sheet of paper, so as to get an imprint of each finger from one side of the nail to the other. Label and date each person's imprint.

7. Take your pulse several times during a day, as the first thing in the morning, before and after a meal, and before and after violent exercise, and report the results.

8. With a clinical thermometer find your temperature, under your tongue. If several persons use the thermometer, be sure it is thoroughly cleansed each time it is used.

9. Bring a beef, or sheep, heart to class, and show its structure and its four chambers.

10. Prepare a paper on the body temperature of different classes of animals.

11. Prepare a paper on the breathing apparatus of insects and fishes.

12. Count the number of inspirations you carry out, in 60 seconds, both before and after exercise.

395. References.— Same as in Chapter XX.

CHAPTER XXII

THE NERVES AND THE SENSE ORGANS

396. The Nervous System.—While we study the human body part by part, and system by system, we must remember that it is not simply one part added to another, but that it is a **complete organism,** and that its many parts act together. The eye, hand, and foot have each a separate duty, but all can combine to do one thing, say, to make a "drop kick" in football, or to run an automobile. The movements of the eye, hand, and foot are under the control of the **will**; but there are many activities of the body that go on without our notice and without any effort of the will. Examples of these are the beating of the heart, the movements of the ribs and diaphragm in respiration, the secretion of saliva, gastric juice, and bile when they are needed. Our food is under our control until the muscles of the throat have contracted in swallowing; after that it is in control of **involuntary** muscles. How does each organ of the body know when to perform its function, how much effort to put forth, and when to stop? The answer is that the different organs are **in communication** with one another, like the houses on a telephone line. When there is a need for the performing of a function, the organ concerned receives notice of the need, and sets about doing its particular work. When the demand is over, the organ receives notice, and stops its work. This regulation of the body by communication between its parts is the work of the **nervous** system.

The nervous system is studied in **three** divisions:

I. The **voluntary,** or **somatic,** system, which is subdivided for purposes of study into:

(1) The **central** system, including the **brain** and **spinal cord;**

(2) The **peripheral** (pĕr-if′ĕr-ăl) system, including the **cranial** and **spinal nerves** and their branches.

II. The **involuntary,** or **visceral** (vĭs′ĕr-ăl) system, which presides over our involuntary systems.

The parts of the nervous system are made up of **nerve tissue,** just as muscles are made up of muscle tissue. The unit of nerve tissue is the **nerve cell,** or **neuron** (Fig. 319). This consists of: (1) the **cell body;** and (2) **extensions** of the cell body, especially the **nerve fiber.** The cell body looks much like other cells, except that it is **grayish.** The nerve fiber has a central **axis** which is an extension of the **protoplasm** of the cell body, and, like the cell body, is gray. The outer covering of a nerve fiber is usually white. A **bundle** of nerve fibers is what we commonly call a **nerve.** A nerve message is called a **nerve impulse.**

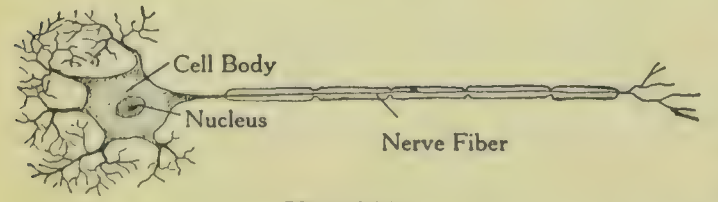


FIG. 319.

A nerve cell, consisting of the cell body, the nerve fiber, and extensions of these.

Nerve fibers are of **three** kinds, according to their **use:** (1) those that carry messages **from** an organ **to** the brain or spinal cord; (2) those that carry messages back to the organs; and (3) those which **connect** the other two.

Nerve tissue may be in **separate** nerve cells, or it may consist of **groups,** called **ganglia** (singular, *ganglion*). The brain and spinal cord consist of large groups of nerve cells; there are smaller groups in different parts of the body.

ELLEN H. RICHARDS (1842-1911). Pioneer of home economics in America.

THOMAS A. EDISON (1847). Inventor of the incandescent lamp and the phonograph.

ORVILLE WRIGHT (1871). Inventor, with his brother Wilbur, of the airplane.

GUGLIELMO MARCONI (1874). Inventor of the commercial wireless telegraph.

397. The Brain.— The brain is the largest part of the nervous system (Fig. 320). It weighs about 3 pounds; in exceptional cases, 4 pounds. In other mammals there is a distinct front portion, or *forebrain*, called the **cerebrum.** In man this is the **upper** portion. There is also a *midbrain* and a *hindbrain.* The hindbrain consists of the **cerebellum,** the **pons,** and the **bulb.** The bulb is also called the **medulla oblongata.**

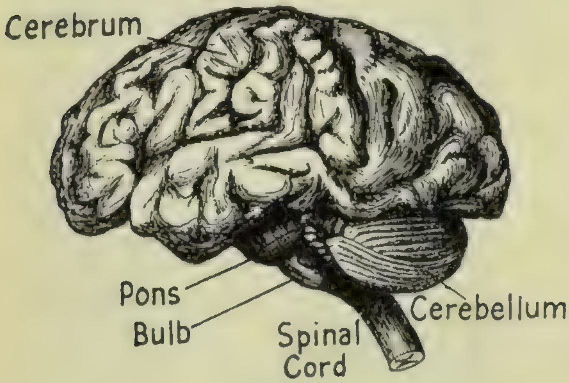


Fig. 320.
A side view of the brain.

The **cerebrum** is gray because of the cell bodies on its surface (§ 396). Its interior is white, and consists of bundles of nerve fibers ("nerves"). The surface of the cerebrum of an adult person has a great many folds, or **convolutions;** these greatly increase its area. The increased area is needed as the cells increase in number. A deep dent from front to back divides the cerebrum into a right and a left **hemisphere.** All the parts of the cerebrum are connected by nerve fibers, and a multitude of fibers connect the cerebrum with the midbrain, hindbrain, and spinal cord, as well as with the **sense organs.**

The cerebrum is the **organ of the mind.** Through it we get the **sensations** of heat, light, sound, touch, and taste, and the use of our voluntary muscles. Twelve pairs of nerves (*cranial* nerves) pass from the front of the cerebrum **directly** (that is, without going through the spinal cord) to the head, neck, and trunk.

The **midbrain** is a rounded body under the cerebrum, and connecting the forebrain with the hindbrain.

The **cerebellum** (meaning, "little cerebrum") is the largest body of the hindbrain, and occupies most of the space inside the "base of the skull." It is covered over by the back lobes of the cerebrum, and its surface looks much like that of the cerebrum. The cerebellum seems to have control of muscular movements, making the muscles contract properly and in pairs (§ 357). It thus causes the movements of the body to be orderly and regular.

The **pons** is in front of the cerebellum, and consists largely of bands of nerve fibers. These connect the cerebrum, cerebellum, and bulb.

The **bulb** is really the enlarged upper end of the spinal cord, although it is within the cranium. It is below the cerebellum, and consists of ganglia of the nerve cells and nerve fibers that connect the spinal cord and the brain.

398. The Spinal Cord.—The spinal cord (Fig. 321) is about $\frac{2}{3}$ of an inch thick; in the adult it occupies the cavity of the spinal column down to the bottom of the 20th vertebra. The cord is not round, but has two lengthwise depressions (one in front and one in back) that make a cross section of it look like a capital **H.** The outside of the spinal cord is white, from the coverings of its nerve fibers; the inside consists of gray cells. At its upper end the cord enters the skull, and is enlarged to form the **bulb;** the lower end is continued in large **nerve trunks,** which supply the hips and legs.

399. The Visceral System.— Besides the voluntary nervous system, consisting of the brain, the spinal cord, and their systems of nerves, the body has another group of nerve structures, called the **visceral system.** This is smaller than the voluntary system, but it is very important, for it has control over the **internal organs,** such as the stomach, liver, and others. It also controls the skin, with its blood vessels and sweat glands. In addition, it has charge of other parts of the body not reached directly by the brain and spinal cord.

The visceral system is not independent of the central system, but is a part of it. This is well illustrated by the fact that strong emotions, such as fear and anxiety, allay or prevent digestion. The action of the visceral system upon the blood vessels is well illustrated by the phenomenon of **blushing.**

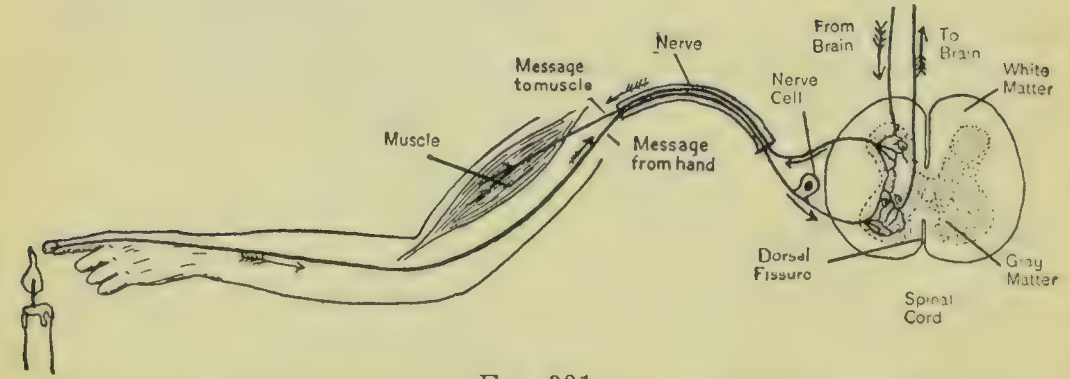


FIG. 321.
The spinal cord and the path of messages between it and the hand.

400. The Nervous System as a Whole.— How are the "nerve connections" made that put an organ, such as the foot, into communication with the brain? We might "guess" that the nerve fibers are fastened together; but this does not seem to be true. So far as we know, there is no actual **joining,** or at most only a slight joining, of the nerve cells. The cell body and the nerve fiber have each a number of branches. By the **interlacing** of these branches of one nerve cell with those of another there is formed a **conduction pathway,** much as if we put the fingers of one hand **loosely** between the fingers of another.

The pathway along which a nerve impulse must travel is thus one having places in it at which the impulse meets with **resistance** (§ 189).

Because the resistance at some places is greater than at others, the nerve impulse finds a **preferred pathway**, a "path of least resistance." We may compare the nerve impulse with a **traveller.** While the traveller is inexperienced, one route looks as good as another; but when he has taken a good many trips, he finds certain routes give better connections than others, and chooses those.

How are these "preferred pathways" laid out for our nerve impulses? Some of them we **inherit**; the same impulses came to our ancestors long, long ago. But others of these pathways we develop by **experience.** As a given message moves again and again through the same chain of nerve cells, it finds the path easier and easier to follow, until it finally falls into that path, automatically, as soon as it starts on its journey to or from the central system.

401. Voluntary and Reflex Action.— Voluntary acts are those for which we use the **will**; they get their impulse from the cerebrum. If we **will** to open a book, our muscles obey the cerebrum, and open it; if we will to close it again, the muscles carry out the operation. We have the power of **choosing** what movements shall be made by our **voluntary** muscles. Other muscular movements, such as those of the stomach (§ 364), are **involuntary.** Involuntary action is also called **reflex action.**

Not only the movements of **internal** organs, but many of our **external** movements, are reflex. Thus, the blinking of the eyelids, which is for the purpose of cleaning and moistening the eyeballs, is not voluntary. If it were, we might forget to do it. When you put your hand against a hot stove (Fig. 321), you jerk away your hand before you feel the pain. The jerking motion is a reflex act. In order that your **mind** may know that the stove is too hot, the nerve message must get to the **cerebrum**; but the lower part of the nervous system gets word of the injury before the brain does, and sends the message to the muscles to jerk your arm away.

402. Habit.—Why is it that the control of so much that the body does is left to involuntary, reflex action? We can understand some of the reasons very readily. In the first place, reflex action relieves the cerebrum and the mind of a great deal of work. Thus, by being freed from the duty of controlling the internal organs, the cerebrum has time to do a much higher kind of work for the body. It can be used for getting new impressions; we can **learn,** and we can **think. Memory** belongs to the cerebrum alone. But the work of getting new impressions is very taxing to the cerebrum, so there is a device for saving work here also. If we voluntarily perform a certain act again and again, our memory becomes more and more definite regarding the act, and the brain needs to make less and less effort to have it repeated. So we finally acquire the power of reflex action in doing a thing that was at first entirely voluntary. Such acts are called **acquired** reflex acts, to distinguish them from reflex acts that are natural to us. Acquired reflex acts are **habits.**

While nature makes a good act easier and easier to perform, it visits its punishment upon us if we perform bad acts, for they become easier and easier, too. Finally, a bad act, which we performed at first only by making a conscious effort, becomes a masterful, evil habit that we find very hard to break. We need to keep up our **power of forming habits,** and to use that power, **deliberately,** to form **good** habits, so that it will be easier and easier for us to do right, and harder and harder to do wrong. If we have the **will** to put a good habit in the place of a bad one, we shall forget the bad one, and be free from it.

How we admire a person who has **perfect control** of himself; whose look is confident, whose hand is steady, whose motions are sure! How much more we admire the person who has control over his **will** so that he does not "lose his head" in an accident, or "lose his temper" over a disappointment; who looks on the bright side of things; who sticks to a hard task; who does not let a bad habit get the better of him; who "keeps his head" in a mob, and does not allow himself to be carried away into a line of action just because others are doing it; who uses the **gifts** nature has given him, and the **will** he has strengthened by daily use, to have an **individuality**!

403. Effects of Alcohol and Tobacco on the Nervous System.—We have already learned of the effects of alcoholic liquors upon digestion and respiration. Because of these effects insurance companies do not insure the lives of heavy drinkers at all. In making out its rates, and the conditions under which it will insure persons, an insurance company does not deal with a few individuals, but with thousands of cases. You may know a man who has drunk whisky, and lived to old age. His case, by itself, proves nothing. But the insurance companies have kept records, now, for many decades, and they **know** how alcohol affects men. Their verdict is that the death rate among drinkers, even **moderate** drinkers, is from 25 to 40 per cent higher than among men who do not use alcohol.

Alcohol works injury to the **whole body**; it does so through the most **delicate** organs of the body, those of the nervous system. Alcohol injures the **nerve cells**; in the steady drinker it causes them to break down, and to become useless. Muscles that were under control become uncertain, and the hands tremble. The user of alcohol takes a drink to "steady" his nerves, but he can steady them for only a little time. He thus develops a habit that requires the constant use of alcohol, and the alcohol injures his body more and more. In losing their self control with regard to alcohol, many drinkers lose their honesty and their abhorrence of crime. It has been found true again and again that criminals drink strong liquor to nerve themselves for horrible acts.

People sometimes say that the drinker injures only himself, but this is not true. His friends and his family suffer with him, and he swells the numbers of the insane and dependent — people for whom society has to care, but who can give back nothing in return.

We have already learned that the **cigarette** injures the organs of respiration; its effect is much worse upon the nervous system, especially upon that of young people. The nerve cells of the boy who uses cigarettes do not grow properly, and the chances are against his "making good." Instead of becoming alert and ready, he is more likely to lose ground, and to become backward and indifferent. Only a small per cent (less than 7) of the school children who smoke are able to keep up their work. How can such children expect, later, to satisfy their employers or customers, and to make a good living? It is not for nothing that the best athletic trainers refuse to let athletes use tobacco. An athlete needs steady nerves, "wind," strength, and the ability to decide quickly; if he wishes to develop these qualities to their fullest extent, he should let tobacco alone.

404. Exercises.— 1. What advantage does the body derive from a central nervous system? What advantage does a telephone system derive from a central station? Is there any disadvantage in either case?

2. How do you account for the fact that you can recall a "forgotten" event by a hard effort of the memory?

3. A foreigner who speaks our language perfectly when at ease often falls into his native speech when excited. Tell why.

4. Why is the order for the closing of the eyelids, when we fear an accident, not left to the cerebrum?

5. If the cerebrum of a person were removed, and he lived, could any of his functions go on? What ones could not?

6. Why is goodness connected in our minds with cleanness?

7. How does a baby learn to speak with a rough voice, or a pleasant one? How to speak one language rather than another?

8. Name several reflex actions of the external organs.

9. Suppose that you have a bad temper; suggest how you could get control of it. What would you suggest to a person who always "answers back," as a way to cure himself? To one who uses cigarettes?

10. Why does your mouth water when you smell a good dinner?

How do the salivary glands know when to secrete the saliva? Does the "watering" of the mouth serve any good purpose?

11. How are nerve impulses started, and to what organ are they carried, when you "read over" your lesson for the first time? What has occurred when you can recite it perfectly?

12. Why ought the performing of experiments with oxygen, in the laboratory, help you get a better idea of this gas than merely reading about it? Give the reasons.

405. The Special Senses.— By the special senses we mean **touch, taste, smell, hearing,** and **sight.** The organs of the special senses are the skin, the mouth and tongue, the nose, the ears, and the eyes. Each of these possesses nerve cells that carry to the brain special messages from the **outside** world. The eyes send **light** impulses, the ears, **sound** impulses, the finger tips, **feeling** impulses. As these impulses come to the brain, **we,** that is, **our minds,** must interpret them: we must know by our judgment and our "common sense" what the impulses mean. The messages that come to the brain produce **sensations** in the mind. The ability to interpret the messages correctly comes to the mind through **experience.** See § 208. When the nerve cells in the finger carry to the brain an impulse started by a needle point, the mind has the sensation of **touch,** or of **pain.** The usual impulses sent to the brain from the stomach produce in the mind the sensation of **hunger;** the usual impulses sent by the throat produce the sensation of **thirst.** We call the sensations that come from impulses **within** the body, **general** sensations; those from impulses **outside** the body, **special** sensations.

406. Touch.— In the skin, and in the mucous membrane of the tongue, are little elevations that contain the **touch corpuscles** (Fig.

322). Inside the touch corpuscles are the ends of the nerve fibers. When we touch an object, the **changes in the pressure** against the touch corpuscles set up impulses in the nerve fibers. We feel the object as smooth or rough, large or small, sharp or blunt, hot or cold, hard or soft, according to the account which the nerve cells send to the brain.

The sense of touch is not equally good everywhere. Its acuteness depends on the number of touch corpuscles in a given area. We can measure its acuteness by means of the tips of a pair of dividers, or by two pins. The tongue can feel that there are **two** points when they are only $\frac{1}{25}$ of an inch apart; the finger tips, when they are about $\frac{1}{12}$ of an inch apart. The back, however, feels the two points as **one,** even when they are $1\frac{1}{2}$ or 2 inches apart. The **sense of temperature** is also in the skin and mucous membrane.

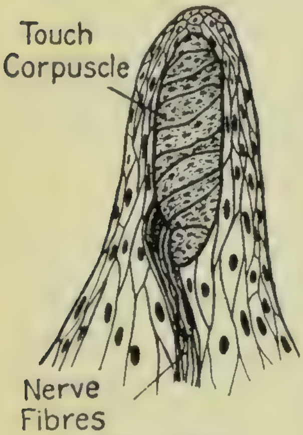


FIG. 322.
A touch corpuscle.

407. Taste.— The nerves of taste end in the mucous membrane of the tongue and the back of the mouth (Fig. 323). Only liquids and **dissolved** substances can be tasted (§ 360); solids cannot get to the taste cells. Some parts of the tongue are much more sensitive than others, and different parts of the tongue recognize different tastes. There are sweet and bitter tastes, sour and salty tastes, and combinations of these. Some of the nerves of taste end in special structures called **taste buds.** The "buds" contain little cavities that open into the mouth; in the openings of the cavities the "taste cells" come into very close contact with the food solution.

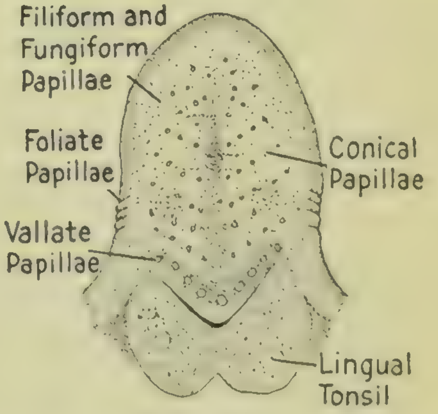


Fig. 323.
The tongue, with its taste papillae.

The sense of taste can be greatly developed by use. Professional "tasters" of tea, coffee, and foods become very skillful. A good sense of taste is a valuable protection, for it enables us to judge of the quality of food before we swallow it. What we call the "taste" of a substance is often a combination of smell and taste. Some of the "strong" brands of cheese, for example, have a mild taste if we hold our noses while eating them.

408. Smell.— The sense of smell, like the sense of taste, is at the opening of the digestive tract. But the sense of smell guards our organs of respiration as well as those of digestion, for it passes upon the good or bad quality of the air we breathe. Smell can recognize only gaseous substances, and not all of those. Thus, air, oxygen, and hydrogen are odorless. The nerve cells that send odor messages to the brain end at the **olfactory cells**; these are in the upper part of the nose cavity (Fig. 324).

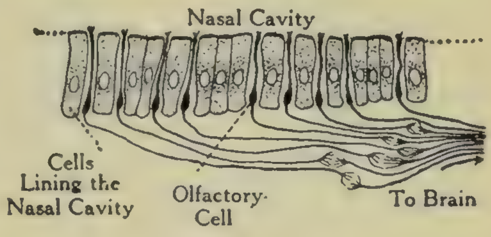


Fig. 324.
The olfactory cells, which bring us the sense of smell.

Wild animals and primitive men have an acute sense of smell, and can easily recognize odors at some distance, but civilized man usually has the sense in only a blunted form. For him all odors are classified as pleasant, or unpleasant, and he does not distinguish them further. The trained scientist often develops his sense of smell to a high degree, so that he is able to recognize substances by their odors even when very small amounts are present.

409. The Ear.—The **ear** (Fig. 325) is the organ of hearing; in it are the nerve cells that respond to sound waves. The ear has **three divisions**: (1) the **outer** ear; (2) the **middle** ear; (3) the **inner** ear.

The **outer** ear is a funnel-shaped structure made of cartilage and skin; it is used for the purpose of collecting sound waves. The tube that leads to the middle ear is called the **auditory canal.**

The **middle** ear is a hollow in the temporal bone (Fig. 303); it is called the **ear drum,** or *tympanum.* Between the middle ear and the auditory canal is stretched the **tympanic membrane,** which corresponds to the "drum head." A chain of 3 small, connecting bones stretches across the middle ear. The first of them is attached to the tympanic membrane, and the last reaches to the opening of the inner ear. The middle ear is connected with the throat (§ 385) by the **Eustachian** (yū-stāk'ē-ăn) **tube.** This tube allows the air to press on the inside of the tympanic membrane, and to balance the pressure of the air in the auditory canal. Otherwise a sudden change in the outside air pressure might burst the membrane. When cannon are being fired, the gunners are instructed to hold their mouths open, so that the air shock on the inner side of the membrane may equal that on the outer side.

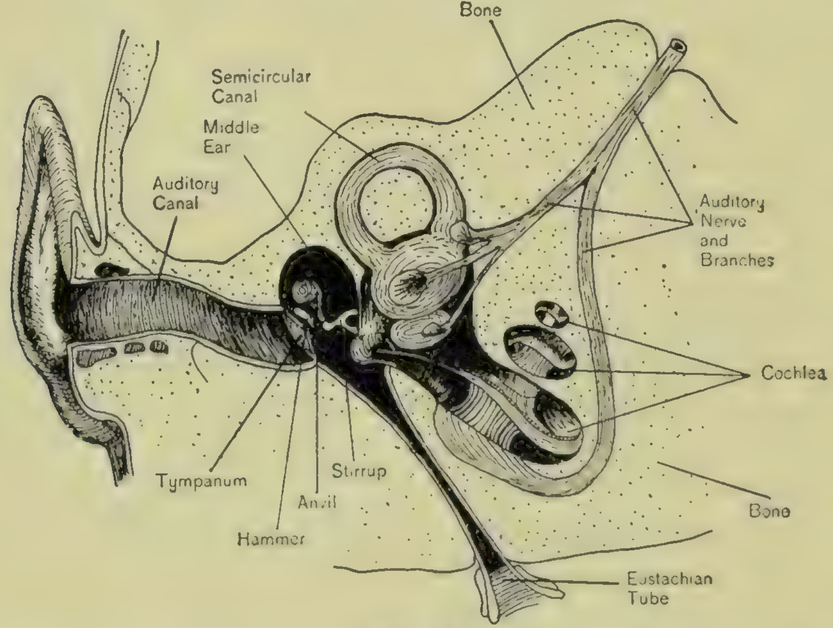


Fig. 325.
A section through the temporal bone, showing the parts of the ear.

The outer ear gathers the sound waves, and the middle ear passes the vibrations on to the **inner** ear, the real organ of hearing. The inner ear is filled with liquids. It is separated from the middle ear by a membrane; to this membrane the last bone of the middle ear is attached. As the membrane is made to vibrate, it gives its motion to the liquids of the inner ear. The **vestibule** is the first chamber of the inner ear. The **cochlea** (kŏk′lē-ă) is like a snail shell, and this fact gave it its name. It is the part of the ear that contains the fibers of the auditory nerve.

The inner ear also contains the **semicircular canals.** These are not part of the hearing apparatus, but they tell the brain in what direction the body is **leaning,** and so help in keeping the body balanced. How do they help an **aviator?**

The ears should be cared for intelligently. Sharp objects should not be put into them, and they should never be pulled or "boxed," for fear that the "drum head" may be burst. The **earwax** is intended to keep insects out of the ear, and should not ordinarily be removed until it comes out of the auditory canal. Clean, warm water will remove earwax better than anything else. An unusually large secretion of earwax sometimes causes dull hearing and deafness, but no one except a physician ought to try to remedy the trouble.

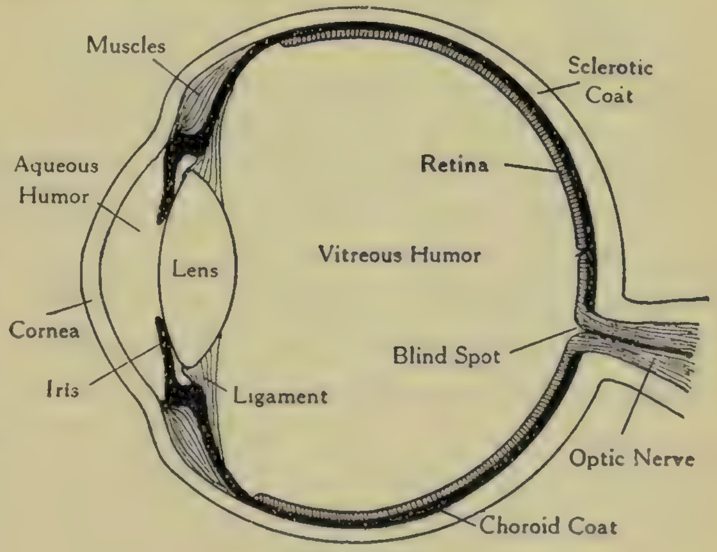


Fig. 326.
Parts of the eye.

410. The Eye.—In many respects the eye is like a **camera** (§ 207). It contains a lens, called the **crystalline lens** (Fig. 326), a "shutter," called the **iris,** for regulating the amount of light, a sensitive membrane, the **retina,** for receiving the image, and an arrangement, called **accommodation,** which changes the focusing as objects are near or distant.

The crystalline lens divides the eye into **two chambers** of unequal size. The smaller one is in front, and contains a liquid called the **aqueous humor.** The larger chamber is filled with a jelly-like liquid called the **vitreous humor.** These two humors keep the eye round and full. They and the crystalline lens together make up a **double-convex** lens (§ 206), and throw on the retina an **inverted image** of the object.

The outside coating of the eyeball is tough and strong; it is called the **sclerotic** (sklĕr-ot′ĭc) **coat.** It is opaque everywhere except in front, where it becomes transparent, and is called the **cornea.** The "white of the eye" is the visible part of the sclerotic coat. The **choroid** (kō′roid) **coat** is inside of the sclerotic coat. It is dark, and acts like the dark interior of a camera in absorbing light, and so preventing the light from being reflected back and forth inside the eye. The **iris** is a part of the choroid coat; it acts as a curtain for the eye, and gives the eye its color. The **pupil** is an opening in the iris. It is controlled by two sets of muscles, which open or close it, according to the amount of light. In the **cat** the pupil becomes a narrow **slit,** when the light is bright.

The **retina** (rĕt′ĭ-nă) is the innermost coat of the eye; it covers the back portion of the choroid coat. The retina is very complex. It arouses light impulses in the optic nerve. The **blind spot** of the eye is the place where the optic nerve enters the eyeball.

The eyeball is held in place, and moved about, by means of 6 small muscles. The transparent, front portion of the eye must be kept moist and clean, hence the eye has **lachrymal** (lăk′rĭ-măl), or "tear," **glands** (Fig. 327). These secrete tears, and pour them over the eyes. The tear glands are in the upper, outer corners of the eyes. Their secretions are carried by a **duct,** or tube, into the nostrils. When the tears are secreted in larger amounts than the ducts can carry off, we "cry"; the tears overflow the lids.

411. Accommodation.—The crystalline lens and cornea together form the most important **focusing** part of the eye. The crystalline lens differs from a glass lens in that it is very **elastic**; if left to itself, it becomes **more convex.** On this fact accommodation depends. The lens is held to the choroid coat by a ligament called the **suspensory ligament.** Ordinarily this ligament is stretched tight by the choroid coat, and **flattens** the lens. When the lens needs to be more rounded, the **ciliary muscles,** which are attached to the sclerotic coat, draw the choroid coat forward. The result is that the suspensory ligament is loosened, and the lens is allowed to become more convex. This power of the eye to **change the curvature** of the lens is **accommodation.**

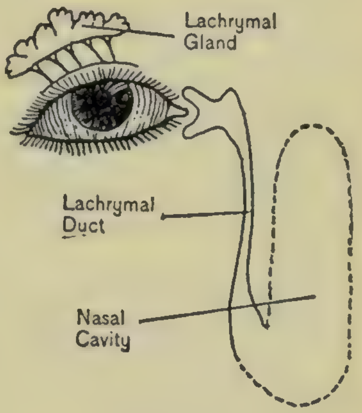


Fig. 327.
Relation of the lachrymal gland to the eye.

When light from a **distant** object, such as a tree, comes to us, the light rays are **almost parallel**; hence the lens, though flattened, can bring the light to a focus on the retina (Fig. 198, § 206). But when you look at a **near** object, the light rays from any point of the object spread out, and make a **large angle** with one another; hence a lens with a more rounded surface is needed to bring the rays to a focus. As we become older, the crystalline lens becomes less elastic, and does not become so rounded when it is released. We are, therefore, likely to lose some of the power of accommodation.

412. Near- and Far-Sight.— When a normal eye is at rest, it is in focus for *distant* objects. For close objects, accommodation must be used. A "**near-sighted**" eye (Fig. 328) cannot see objects distinctly at more than about 10 inches' distance; at a greater distance, the focus

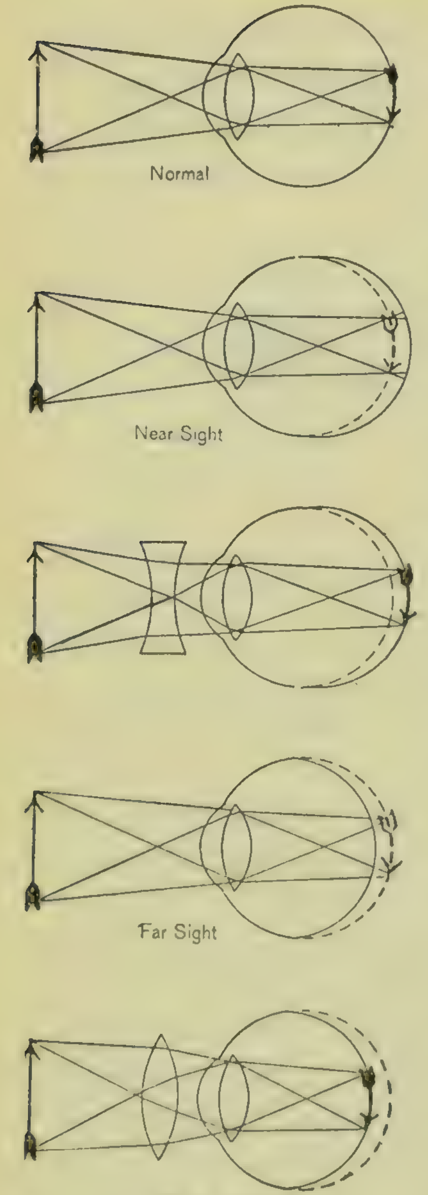


Fig. 328.
Diagram of a normal eye, a near-sighted eye, and a far-sighted eye. The near-sighted eye needs a concave lens; the far-sighted eye, a convex lens. The dotted curved lines show where the retina would be, if the defective eye were normal. The solid, curved arrows show how the light rays are brought to a focus by the proper eye-glasses.

is formed **in front of** the retina. Hence the light rays have crossed before reaching the retina, and the image is blurred. The remedy for short-sightedness is a **concave** lens of the right curvature. This throws the image farther back, upon the retina.

In **far-sighted** vision the object to be seen must be more than 10 inches away; otherwise the image will fall **behind** the retina. Of course this is impossible, since the retina is opaque; but the image on the retina is blurred, because the light is not yet at a focus. The crystalline lens prevents far-sight, if it has full power of accommodation. When this power is lessened, convex lenses are needed to help the crystalline lens.

Astigmatism (ā-stĭg′măt-ĭsm) is a defect of vision that is due to a lack of sufficient curving, or a flatness, in some part of the cornea or crystalline lens. The muscles of the eye keep trying to adjust the eye and the lens, so as to make a distinct image, and become worn out in the attempt. Glasses for astigmatic eyes are made to correct the particular trouble of each eye, and are of no use unless an expert oculist fits them. There are few errors of vision that the oculist cannot correct, and we should consult him at once if we have any difficulty with our eyesight. Poor vision causes a constant strain upon the eyes, with headaches, inflammation of the eyes, and nervousness. Wonderful improvement in the general health often follows the wearing of the right glasses, and the relieving of the eye from strain. The eye is so delicate that if it is upset the whole nervous system feels the effect.

413. Protection and Care of the Eyes.—The eye is admirably protected. It is set into sockets in bones of the skull, so that it is shielded on all sides except in front. The sockets are lined with fatty tissue covered by a double membrane. The fat and membrane not only make the socket smooth, but they also form a soft cushion for the eyeball, in case it is forced inward by a blow.

The eye is protected **in front** by the eyebrow, the eyelashes, and the eyelids. The bone forming the brow projects over the eye like a roof, protecting it against blows from above. At the same time the hairs of the **eyebrow** act like eaves troughs, and drain off perspiration, so that it does not run down into the eye. The **eyelashes** shade the eye from "high light," and keep out dust. The **eyelids** move with incredible speed when the eye is in danger, so that the "twinkling of an eye" is really a very short space of time. Experimenters have again and again owed the preservation of their eyesight to the fact that reflex action closed their eyelids before the pieces scattered by an explosion could travel to the eye.

The eyelids are lined with a very sensitive membrane, the **conjunctiva.** The same membrane covers the front of the eyeball. When we get a cinder into our eye, and it hurts badly, we ought to remember that the pain is the conjunctiva's way of telling us that the eye is in danger, and that we must remove the trespassing cinder.

We should never rub our eyes with our fingers, unless we are certain that the fingers are **clean.** We should read only in a good light; but the light should not be too bright. **Direct sunlight** is too bright. If we read or study by lamplight, either our eyes or the lamp should be shaded, best by a **green** shade, and the lamplight should come to our book from the **side,** or over a shoulder. We ought not to read in a moving train or street car for more than a little while. The jarring of the car causes the book to shake, and the eye is strained in trying to follow it. We ought not to read while lying down; the position is awkward, and trying to the eyes.

414. Summary.— The **nervous system** regulates the body by providing communication between its parts. It consists of the **voluntary** and the **visceral** systems.

Nerve cells consist of **cell bodies** and **nerve fibers.** A "nerve" is a bundle of nerve fibers.

The **brain** consists of forebrain, midbrain, and hindbrain.

The **cerebrum** is the forebrain. It communicates with the body through the midbrain, hindbrain, and spinal cord, but it has also direct connection, by means of **cranial nerves,** with parts of the head, neck. and trunk. The **cerebrum** is the **organ of the mind.**

The hindbrain consists of the **cerebellum, pons,** and **bulb.**

The **spinal cord** is enclosed in the spinal column.

The **visceral system** controls the internal organs and the skin.

Voluntary acts are directed by the cerebrum.

Reflex acts are either natural, or **acquired.**

Habits are acquired reflex acts.

Alcohol injures the whole body by attacking the nerve cells.

Tobacco prevents the nervous system of young people from developing properly.

The **special senses** are touch, taste, smell, hearing, and sight.

Touch is due to nerve fibers in the **touch corpuscles.**

Taste is possessed only by dissolved substances.

Smell originates in nerve fibres of the olfactory cells.

Hearing is due to impulses sent by the auditory nerve.

Sight is due to impulses from the optic nerve.

Accommodation is the power of the eye to alter the curvature of the crystalline lens.

Near-sighted eyes need concave lenses; **far-sighted,** convex lenses.

415. Exercises.— 1. Name as many **sensations** as you can, and tell what impulses produce them.

2. How would you set about cultivating your sense of smell, so as to make it acute?

3. Name the organs through which a sound must travel before it reaches the auditory nerve.

4. Name all the structures through which a ray of light must go to reach the optic nerve.

5. If it is true that the image on the retina is inverted, why do we not see objects upside down?

6. A fly held near the eye looks as large as a man who is down the street; how do we know it is not really as large?

7. When a stick with a spark at one end is swung about in a circle, the eye "sees" a continuous ring of light; why? Why does a meteor ("shooting star") seem to have a "tail"? See § 159.

8. Why does it rest the eye, after we have been reading, to look at a distant object?

9. Adenoids, and colds in the throat, often cause deafness; what part of the ear do they stop up first?

416. Projects.— 1. Get a small amount of saccharin, and let the class try the taste of a very tiny amount and then of a larger amount. Account for the results.

2. Show the class the effect of a dark closet, and then of a bright light, upon the dilation of the pupil of your eye. Use a cat for the same purpose.

3. Prepare a paper on the "compound" eyes of insects.

4. Have an oculist show you how to use his chart for testing for far-sight and near-sight, and carry out the test with several members of the class.

5. Blindfold a member of the class, and with a pair of dividers test his finger tips, tongue, lips, and neck, to determine how far apart the dividers must be for him to recognize the tips as two points.

6. Demonstrate to the class the correct and incorrect way of using a table lamp for reading or study.

7. Bring to class the eye of a cow or sheep, or use a model of an eye, to demonstrate its parts.

8. Prepare a paper on color blindness.

9. Prepare a paper on the ways of maintaining good eyesight.

10. Consult an architect regarding the principles of "indirect lighting," and present them to the class.

11. Blindfold a member of the class and have him hold his nose and report the taste of several strong-odored foods, such as cheese and sausage.

12. Prepare a paper upon the substitutes for sight in the case of the blind.

417. References.—Same as for Chapter XX.

CHAPTER XXIII

HOW TO LIVE

418. The Body in Health.—The literal meaning of health is **wholeness,** the condition of the body in which all its organs can do their work properly. We know of many persons who are seeking to regain health after they have lost it, but comparatively few who have a program that calls for the maintaining of real health when they have it. We have already considered some of the things necessary for this "positive" health. One of them is **good air**; air of the right temperature, movement, moisture, and purity. Another is **good water,** for drinking, bathing, and laundry purposes, and for the removal of sewage. A third requisite of health is **good food,** properly chosen, and in quantities suitable for our age and occupation. A fourth necessity for good health is proper **muscular exercise,** taken not only so that our muscles may remain strong and our food digest properly, but also because we **enjoy** physical activity in the out-of-doors. A fifth means of maintaining health is **good habits**—the result of the regular exercise of the will in avoiding what is harmful, and in choosing what is good.

With a health program like that just outlined, we can go far toward success. We must not, however, overlook one other element in the maintenance of our own health, namely, the health condition of our **neighbors** and of the **community** in which we live.

419. The Causes of Disease.—We have already learned (§ 86) that **bacteria** are minute organisms, generally classed as plants rather than animals. They cause the decay of dead animals and plants (§ 30), and produce diseases that are "catching," or **contagious.** All disease-producing agents are not, however, **bacteria;** some of them are minute, one-celled **animals,** called **protozoa** (prō′tō-zō′ă). Thus, malaria and yellow fever are caused by protozoa. It is impossible for us to escape from germs, for they are everywhere about us: on the ground, in the air, and in our houses; but, fortunately for us, all germs do not cause disease. Most of them live their own lives without interfering with ours. In the outside air we should rarely meet with injurious germs were it not that they escape from the bodies of animals and of persons who are sick. So the germs we usually have to fear are those that are carried, in food or by contact, from animals to persons, or from one person to another.

The "germ theory" of disease did not gain immediate acceptance when it was first stated, for men could not believe that organisms so small could do so much mischief. But the patient labor of one investigator after another proved that the theory is correct. We now **know** that germs are responsible for smallpox, measles, diphtheria, scarlet fever, typhoid fever, tuberculosis, influenza (la grippe), malaria, yellow fever, pneumonia, lockjaw (tetanus), mumps, cholera, leprosy, and the plague. It takes a definite kind of germ to cause a given disease; no other germ will "do just as well." But the ways of different kinds of germs are not at all alike; it is often very hard for the investigator to know just how each kind of germ gets into the body, and how it does its work. Thus, it turns out that while the mosquito called **anopheles** (§ 347), carries malaria germs from one person to another, only the **female** sucks blood, and is responsible for the spreading of malaria.

The science of germs, and of the way in which we can deal with them, is **bacteriology.** The science of keeping the body in good health is **hygiene.** The study of the conditions and surroundings that make for the health of the body and of the community, is **sanitation.**

Germs, like other living organisms, grow rapidly when the conditions for life are favorable. They need animal or vegetable material for food; they need moisture; they need a favorable temperature. Germs often find these conditions in our solid food, in milk, in water containing organic matter, in the filth of the streets, and in the animals: vermin, pets, and domestic animals, that make their home with man. From food, and water, and animals, then, disease germs are transferred to man. In the body of man they find conditions favorable, and thrive enormously. The stomach secretion kills many, but certain kinds are able to get through the stomach. Some find favorable conditions in the warm, moist cells of the throat and lungs; others, still, get into the blood through cuts and scratches in the skin. When we think of how constantly we come in contact with objects that contain harmful germs, we are impressed with these facts: (1) how efficient our skin is in keeping out the invading army of germs; (2) how important it is to wash the skin, especially that of the hands, so that we may remove the germs before they get into our food; (3) how necessary it is to keep the nasal passages and the mouth (including the **teeth**) **clean,** so that germs may not develop there, and spread disease to the other parts of the body.

Why do not the germs of disease destroy man at once? The answer is that there are two sides to the battle; the body has its **defenders,** as well as its enemies. One of these is the army of **white corpuscles,** which destroys many of the disease germs that get into the blood. We have already seen that the white corpuscles are not only in the blood, but get through the capillaries into the lymph. If a wound is made in the skin or mucous membrane, the white corpuscles do their best to destroy the germs that enter the wound. The body has not only the white corpuscles to defend it, but also produces certain substances that act as **germicides** ("germ slayers"). A great part of the reason why we need to keep the body rested, well-fed, and strong is that it may have an abundance of vigorous white corpuscles, and that it may produce the right germicides for the germs that attack it. Yet, in spite of everything that the body can do, some dangerous bacteria may get past the body's lines of fortifications; we then have a **disease.**

The effect which disease germs have upon the body is due not so much to the germs themselves as to the **substances** that the germs produce. These substances are violent **poisons,** called **toxins**; they injure the cells of the body much as **strychnine** or other poisons would. **Ptomaines** (tō′mă-ĭns), which cause so-called ptomaine poisoning, are toxins produced in the decay of foodstuffs. The disease germs that we take into the body when we are "exposed" to a disease are not numerous enough to produce much toxin, so there is usually a period of time, called the **incubation period,** during which the germs are multiplying, and are producing enough of the toxins to give us the symptoms of the disease.

420. The Dangers in Food.— If the body were unprotected, a single germ might cause a disease. But this is rarely possible. A **few** germs are usually destroyed at once by the blood. But a large number (many millions) may be introduced into the body in a single bite of bad food, or in a mouthful of infected water. So we need to be very careful about the food we eat. Only persons with clean hands and clean clothing should prepare and handle food, and food should be stored only in clean, protected places (Fig. 304). If customers were clean themselves, and were particular about the cleanliness of what they buy and use, their groceries, meat markets, bakeries, fruit stores, candy kitchens, laundries, milk depots, etc., would be clean too.

We must be particular, also, about **tainted,** or decayed, food. Overripe fruit is always to be suspected. **Milk** is especially liable to infection (§ 340). Ever so many epidemics of children's diseases, such as scarlet fever and diphtheria, have been traced to an infected milk supply. Milkmen having the diseases in their own families have again and again been found delivering milk to other families. Typhoid fever and tuberculosis are likewise spread by infected milk. If we buy milk from a small dairy, we should visit the dairy, or ask some competent person to do so, to see if the conditions are sanitary, and if the cows are healthy and well fed. If we buy in a large city, and cannot inspect the supply directly, we should ask the health authorities to make frequent examinations of the milk, so that we may be reasonably sure that it is safe. In most cases children can digest **pasteurized** milk (so called from the celebrated French scientist, Pasteur). The process of pasteurizing is simple and inexpensive, the apparatus consisting only of a covered pail, with a hole in the cover for a thermometer. The bottle containing milk is placed in the pail, the pail is filled with water almost to the mouth of the bottle, the cover and thermometer are put in place, and the pail is heated. A temperature of 68.3° C. (155° F.) maintained for half an hour, or of 77° C. (170° F.) for 5 minutes, kills the disease germs of the milk. The milk is then cooled rapidly, and stored in a refrigerator. The bottles used for the feeding of babies often spoil otherwise good milk (Fig. 329). Those with a long, slender rubber tube are especially dangerous: germs (some of them deadly) collect in the tube, and are not easily removed.

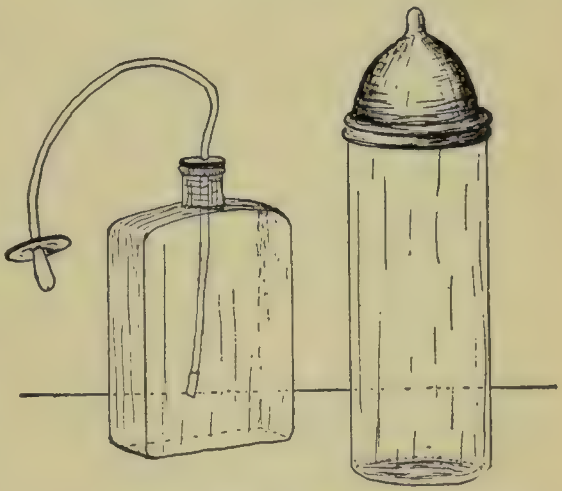


Fig. 329.
The wrong and the right kind of nursing bottle.

421. The Control of Typhoid.—Typhoid fever is one of man's most serious diseases. There are perhaps 250,000 cases of it in a year in the United States alone, with upwards of 25,000 deaths. The bacteria that cause it are taken into the body through the mouth, in food or water. In the small intestine they multiply rapidly, and produce **toxins** that pass into other parts of the body. The body waste from the intestines and kidneys of a typhoid patient contains large amounts of the germs. If the germs are not destroyed, they get into the soil and into sewage. From the soil they may get into garden vegetables, and may be carried, by drainage water, into wells. The germs may get into milk from the water with which milk cans are rinsed, or from some one who has the disease, or from some one who handles the milk with dirty hands. If the sewage is emptied into the stream or lake from which a community gets its water, the whole community is in danger of having the disease. Typhoid germs have been found in oysters that grew near the outlets of sewers. In some, or all, of these ways the germs of one who has the disease may find their way into the digestive tracts of new victims.

Vaccination against typhoid fever is an extraordinarily great aid in its prevention, although it is not absolutely protective. The death rate from typhoid has been so greatly reduced within the last few years by our knowledge of sanitation, and by vaccination, that it has come to be classed as a **preventable** disease. Typhoid vaccination offers little discomfort, and should be widely given, especially in rural communities in which the water supply is likely to be uncertain. Before taking a trip abroad, or even traveling in the United States, all young people should take this precaution. Older people are less susceptible to typhoid. Vaccination against typhoid should be an **additional precaution,** not a substitute for sanitary measures.

422. The Danger of Colds.—We often speak lightly of colds; if suffering from one, we say we have "only a cold." But colds need to be included in our list of serious diseases, if for no other reason than that they are so common, and that they lower the working ability of so many people. Colds are also serious because they are often the beginnings of tuberculosis, pneumonia, and diphtheria. The cold does not cause these diseases directly, but it lowers the power of the body to resist dangerous germs.

Colds are communicated from one person to another; the one who has a cold ought to exercise care, so that he may not pass it on to others. A cold that "hangs on" needs a physician's care, especially if it causes difficult breathing and fever. If it is "only a cold," the avoiding of drafts, care in clothing, and the eating of light food, especially of liquid food, are usually all that is needed to cure it. The old saying is that if you "stuff a cold" (that is, *overeat*), you will need to "starve out a fever." But if a cold makes us weak and chilly, a day or two spent in bed will be of the greatest possible help. Time will actually be saved, if we do not work when we are unfit for work.

We often "catch cold" after we have been overheated by the wearing of too heavy clothing, or by living, even for a little while, in rooms that are hot and poorly ventilated. A bad habit, which too many of us have, is that of going into warm buildings, in cold weather, without removing our outer wraps; when we go out again, overheated, we are in danger of serious trouble. Diphtheria is often mistaken for a cold; this fact is one reason why a cold should not be left to chance, but should be treated by a physician.

423. Antitoxins.—The word **antitoxin** means "against toxin." When germs get into the body, they produce toxins (§ 419). To protect itself, the body produces not only white corpuscles and germicides, which kill the germs themselves, but also substances that **neutralize** the effect of the toxins. These are the **antitoxins.** For every toxin that germs produce, the body probably forms an antitoxin. In diphtheria the patient may not be able to produce enough antitoxin to stop the disease, but if he is helped by the addition of some diphtheria antitoxin to his blood, he may win his fight against the germs. Likewise, if one who has been exposed to the disease is treated with antitoxin, the germs may not be able to develop enough of the toxin to cause the disease. The records of many hospitals show that while before the days of antitoxin there used to be 30 to 50 deaths out of every 100 cases of diphtheria, the deaths since the introduction of antitoxin are only from 11 to 18 in 100 cases.

424. Vaccination.—Up to 1800 almost everybody expected to have smallpox, and the loss of life in the epidemics was enormous. Between the years 1700 and 1800 probably 600,000 persons, on the average, died of the disease every year. But the practicing of vaccination and the progress made in sanitary science have combined to reduce the deaths from the disease to comparatively small numbers in civilized countries.

The discovery of vaccination (*vacca* means a cow) was made by Jenner in 1796. Jenner found that the "matter" formed in cowpox (smallpox of the cow), when introduced under the skin of a man, made it possible for the man to be exposed to real smallpox without catching the disease. The man was **immune** to the disease. See Fig. 330. Vaccination usually produces a mild inflammation at the place where the virus is introduced; this is due to the growth of the germs. The germs from the cow are so much weaker than those that come from a human smallpox patient that they cannot produce the dreaded disease, but their presence in the blood stimulates the body to produce the germicide for the smallpox germ.

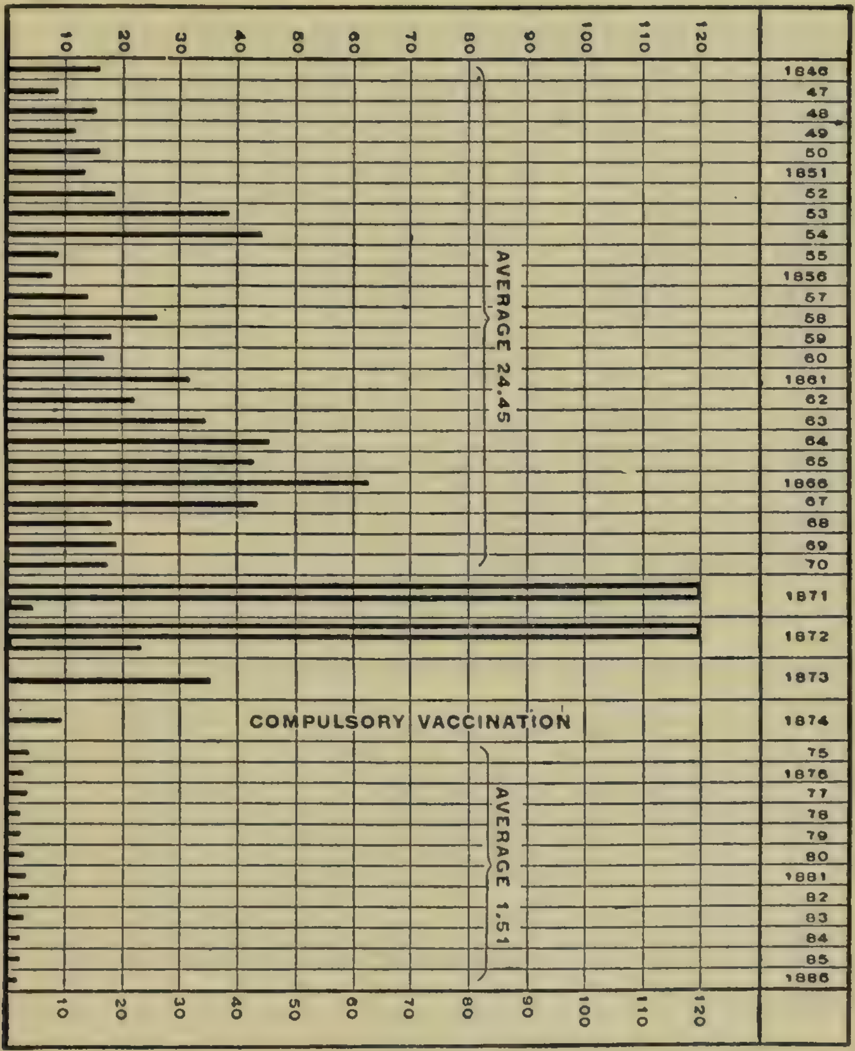


Fig. 330.

Progress of smallpox in Prussia before and after the enforcement of general vaccination. Death rate per 100,000 of population, 1846 to 1886. (From *Hygiene of Transmissible Diseases,* by Abbott, after Schulz.)

The germicide seems to remain in the blood for some time, perhaps for **years** in some persons, and protects the body if other smallpox germs enter. In some persons, however, the germicide disappears in less than a year. We should be vaccinated every few years, or more frequently if there is smallpox near us, in order that the germicide may always be present in the body. If we are vaccinated by a good doctor, with fresh vaccine virus, there is no danger. We should be vaccinated, not only for our own sakes, but for the sake of others. The germs of smallpox live for months in a dry condition; they may be preserved in books, clothing, and letters. Hence we can never tell when we may catch the disease, and give it to our friends and neighbors. We are not wiser than the experience of the last 100 years. This experience teaches us that while sanitary living helps to keep the germs down, it cannot help us if they get into the blood, and if the blood has not prepared the proper germicide for our defense.

425. Quarantine.— Quarantine is the isolation, or setting apart, of a person having an infectious disease, so that the disease may not spread to the community. Quarantine is also used in the case of goods, plants, and cattle, if they are suspected of infection. In the case of a ship coming to our ports, quarantine is the detaining of the passengers and goods on board the ship until the health officials are satisfied that no infectious diseases are being brought into the country. In the case of a house, quarantine means the preventing of persons from going into the house, or more especially from **leaving** the house, for fear that they may carry disease to the community. *Quarantine* means "forty," and comes from the fact that governments of former times, not knowing the incubation periods of germs, nor the time during which infections were possible, detained suspected travelers and goods for 40 days before admitting them into a country.

Do we really understand what we have learned about the spreading of disease by germs? If we do, we shall see at once how valuable and how necessary it is for a city to be able to quarantine persons suffering from dangerous diseases. We shall also be able to see the value of isolation, even when it causes us personally great inconvenience. Suppose that we have smallpox, or that a member of our family has it; we ought still to realize that the community has a right to demand of us that we prevent the disease from spreading to those about us. If we are recovering from scarlet fever, we know we ought not to go to school, or to mingle with other people, until we are absolutely certain that the last of the "scaling" is over. We also know that articles such as milk bottles should not be taken away from a house that is quarantined; they may be infected. By the mingling of infected milk bottles with those going to other houses, a whole neighborhood may be stricken. Sanitary experts say that milk bottles should not be left at an infected house at all, but that the milkman should pour the milk, out of doors, into vessels belonging to the house.

How shall a person having a dangerous germ disease be isolated? In some cases it may be best for him to go to a hospital for contagious diseases; in other cases he may be left in his own house, with his nurse, but all other persons may be required to leave the house. In some cases only **room isolation,** or confinement in a certain room, is advised. In room isolation the cracks about the doors and transoms leading to the remainder of the house should be closely sealed, and the nurse should not mingle with the family. But room isolation is usually unsatisfactory and dangerous; because it is not properly carried out. Real isolation in a room is not ordinarily possible unless the house is a large one, and is so arranged that the patient and the nurse can be removed to a really separate part of it.

The illustrations already given show us that the real value of isolation, like that of other sanitary measures, depends on how it is carried out. If we elect officers to provide a good quarantine, we must support them when they are obliged to use force with some persons who refuse to observe quarantine. Furthermore, we ourselves must obey the regulations of our health department, not merely **in the letter,** so that we may just escape punishment, but in **the spirit,** because we recognize the fact that they are for the greatest good of all the people.

426. Disinfection.— Disinfection means the destruction of harmful germs. It applies to such familiar operations as the boiling of milk and water, the filtering of water, and the washing of hands and clothing, as well as to the treatment of a wound with a **disinfectant,** or the **fumigation** of a room. Preservatives are disinfectants put into food.

The need of careful disinfection during and after disease is much greater than people realize; because disinfection is neglected, preventable diseases continue to attack mankind. Thus, the sputum of a person having tuberculosis or pneumonia ought to be burned; the cloths containing the discharges from the nose and throat during scarlet fever and measles ought to be boiled in hot water; dishes used by a patient, even if he has "only a cold," ought to stand in boiling water for some minutes, so that the germs adhering to them may be entirely destroyed. The need of disinfecting the body waste of typhoid patients has not yet been appreciated sufficiently; it is through these wastes that water is polluted, and that the disease is spread. Experience has taught men that direct **sunlight** is an excellent germicide, hence they have, from time immemorial, hung clothing and bedding in the sunlight for disinfection. Of course a large part of the disinfection that is carried out "in the open" is due to air. Long-continued **drying** destroys germs, as it does other living things. One way in which salt acts as a preservative is that it removes water from the cells of the germs that cause decay. Long-continued **cold** destroys some germs; strange as it may seem, explorers in polar regions are not troubled with colds; the germs of colds cannot live there.

Substances having **poisonous** properties are also used to destroy germs. One of the most frequently used of these chemical disinfectants s **mercuric chloride.** This is a compound of mercury and chlorine;

it is also known as **bichloride of mercury** and as **corrosive sublimate.** It may be purchased in tablets that dissolve readily in water. The "strength" of the solution is usually 1 part, by weight, of mercuric chloride to 1,000 parts of water. Common salt is mixed with the mercuric chloride before the water is added. The solution is very poisonous if taken internally, but it is very efficient in destroying germs that are on the hands, on washable clothing, and on floors.

To disinfect a house by **fumigation,** gaseous germicides are used. The two most common ones are **sulphur dioxide** (burning sulphur) and **formaldehyde.** The burning of sulphur is not an efficient method of disinfection, and is injurious to the furnishings of rooms. It should be displaced by better methods, such as thorough cleaning, special chemical treatment of articles used by the sick, or even the burning of such articles. Plenty of air and sunshine are better than burning sulphur.

Formaldehyde is a much better germicide than sulphur dioxide. An easy way to get the gas into a room is to sprinkle 40% "formalin" solution (a solution of formaldehyde) upon sheets hung on clothes lines in the room to be disinfected. The room should be closed tightly for several hours to give the disinfectant time to complete its work. Separate articles may be disinfected by placing them in a trunk, between cloths wet with formalin solution.

Many **accidents** occur every year because some people keep disinfectants in the family medicine closet, or have them about the house, without a warning label. All such substances should be kept by themselves, in a locked case, and should be distinctly marked. They should also be colored by the addition of a tiny amount of some bright dye, so that no one will mistake them for something else.

427. Science and Community Well-Being.— Now that we have reached the last section of the last chapter of this book, are you interested in a hasty glance backward at the course by which we have come? Why have investigators tried to find out all they could about air and fire, water, soil, food, and plants, electricity, the stars, the weather, acids, machines, and all the list of phenomena and materials we have been studying? Is not the **driving force** within the scientist, first of all to know what is the **truth** about these things? When we know the truth, we begin to change our way of living or thinking in accordance with it—we **apply** science. Even the science we think the farthest removed from our daily life, the study of the distant stars, is of direct use to us, for by it we set our watches and clocks, make our calendars, and lay out our houses and our cities. The fact that a definite amount of air is needed to oxidize a given weight of fuel we apply directly, not only to the construction of dampers and flues in stoves and furnaces, and to the carburetors of gasoline engines, but to the fuel of our bodies—our food.

In the chapters on the human body we have been led again and again from the study of an organ to the study of what helps or hinders the organ in carrying on its work properly; while in this chapter itself (§ 418) we have realized how much the conditions of good health for an individual are affected by the attitude of the community in which he lives. We who live in cities are dependent, for a good water supply and a good food supply, and, largely, for a supply of good **air,** upon the people about us. We cannot be sure of right conditions for ourselves unless the whole community is striving to realize such conditions. The final test of this course of science, as it must be of all knowledge, is its effect upon our own way of living and upon the attitude we take toward the good of the group to which we belong. If you become an engineer, will you do your work better, and with better regard for the public you serve, because you have studied science? If you are to be a home maker, will your housekeeping, and your attitude toward the problems of the community as well, be influenced by what you have learned this year? Good housekeeping, whether in the home or in the community, is not always easy, but it is very much worth while.

428. Summary.— **Good health** is not always possible for the individual without the cooperation of the community.

Contagious diseases are caused by **germs.**

Hygiene is the science that deals with the good health of the body; **sanitation,** especially with the health of the community.

Germs grow in the body because they find favorable conditions. **White corpuscles** and **germicides** defend the body against germs in the blood.

The **effect** of germs is due to the **toxins** they produce.

Food should be handled only with **clean hands** and stored only in **clean places.**

Infected milk may spread disease. If suspected of infection, it should be **pasteurized.**

Typhoid fever germs enter the body through the digestive tract, and develop in the small intestines.

Vaccination against typhoid is a success.

Colds should not be despised, but cured.

Antitoxins are substances the body produces to neutralize toxins.

Smallpox is preventable, if we use **vaccination.**

Quarantine is the isolation of infected persons or goods.

Disinfection destroys germs **after** a disease, so as to prevent a repetition of the disease.

Disinfectants should be plainly labeled.

The **success** of a science course is determined by its results in the lives of students.

429. Exercises.— 1. Why is it better to use a vacuum sweeper than a broom from the hygienic point of view?

2. How can a community guard itself against typhoid fever?

3. Is it hygienic to cough with your face toward other persons? To turn the leaves of a book with saliva-moistened fingers? To put your pencil into your mouth?

4. Why should eaves troughs be kept free from birds?

5. How can drinking water be freed from harmful germs?

6. What objection is there to having much furniture, and draperies and bric-a-brac, in a sickroom?

7. Why should dish cloths and towels be sterilized often?

8. Is inoculation ever used to protect animals from disease?

9. Why does a **dilute** sugar solution, such as a fruit sauce, need to

be so carefully sterilized, while a **concentrated** sugar solution, such as a **preserve**, does not?

430. Projects.— 1. Prepare a paper on the work of bacteria, as a class, in Nature's plan.

2. Collect the facts regarding what your community does for persons having contagious diseases.

3. Consult an architect regarding the way in which a house should be placed to get the greatest amount of winter sunshine in all its rooms, and report.

4. Present the health statistics of your city or community for a year, and explain the changes from month to month.

5. Get the data regarding the best way to disinfect a sickroom after typhoid fever, and report upon them.

6. Prepare a paper upon the ways of making the city more healthful than the country.

7. Make a study of the problem of removing garbage in your city, and report upon it.

8. Make a study of the commercial baking and distribution of bread in your community and criticize it (this means, *judge* it) from the sanitary point of view.

9. Make a study of the grocery stores of your neighborhood and the sanitary precautions taken in them.

10. Make a survey of your neighborhood as a breeding place for flies and mosquitoes, and report upon it.

11. Prepare a report on the work of the public-health nurse of your community, or have the nurse herself tell of her work.

12. Prepare a paper on the life and work of Edward Jenner.

13. Prepare a paper on the life and work of Louis Pasteur.

14. Prepare a paper on the life and work of Robert Koch.

431. References.— Same as for Chapter XX.

APPENDIX

TABLE I. THE METRIC SYSTEM.

1. Length. The unit of length is the **meter** (39.37 in.).

10 millimeters (mm.) = 1 centimeter (cm.).
10 centimeters = 1 decimeter (dm.).
10 decimeters = 1 **meter** (m.).
1,000 meters = 1 kilometer (km.).

Note that the prefix "milli-" means 0.001, as *mill* = 0.001 dollar; "centi-" means 0.01, as *cent* = 0.01 dollar; "deci-" means 0.1, as *dime* = 0.1 dollar. "Kilo-" means 1,000.

2. Square Measure, or **Area.**

100 square millimeters (sq. mm.) = 1 sq. centimeter (sq. cm.).
100 square centimeters = 1 sq. decimeter (sq. dm.).
100 square decimeters = 1 sq. meter (sq. m.).

3. Cubic Measure, or **Volume.** The unit of volume is the **liter,** which is 1 cu. dm., or 1,000 c.c.

1,000 cubic millimeters (cu. mm.) = 1 cubic centimeter (c.c.).
1,000 cubic centimeters = 1 cubic decimeter (cu. dm.).
1 cubic decimeter = 1 **liter** (l.).
10 liters = 1 dekaliter (dl.).
10 dekaliters = 1 hectoliter (hl.).
10 hectoliters = 1 kiloliter (kl.).

4. Weight. The **gram** is the weight of 1 c.c. water at 4°C.; 1 liter of water at 4° C. weighs 1 **kilogram.**

10 milligrams (mg.) = 1 centigram (cg.).
10 centigrams = 1 decigram (dg.).
10 decigrams = 1 **gram** (g.).
1,000 grams = 1 kilogram (kg.).
1,000 kilograms = 1 metric ton.

TABLE II. EQUIVALENTS.

1. Length.

1 centimeter = 0.3937 in.
1 meter = 39.37 in. = 3.28 ft.
1 kilometer = 1,000 m. = 0.6214 mile.
1 inch = 2.54 cm.
1 foot = 0.3048 m.
1 mile = 1.6094 km.

2. Area.

1 sq. cm. = 0.155 sq. in.
1 sq. m. = 10.764 sq. ft. = 1.196 sq. yd.
100 m. square = 10,000 sq. m. = 1 hectare = 2.47 acres.
1 sq. km. = 0.385 sq. mile.

3. Volume.

1 cu. cm. = 0.061 cu. in.
1 cu. m. = 35.315 cu. ft.
1 liter = 1,000 cu. cm. = 1.0567 qt. (U. S.).

4. Weight.

1 gram = 15.4324 grains.
1 kilogram = 1,000 grams = 2.2046 lbs.
1 metric ton = 1,000 kg. = 2,204.6 lbs.
1 short, or net ton = 2,000 lbs.
1 long, or gross ton = 2,240 lbs.
1 grain = 0.0648 gram.
1 ounce (Avoirdupois) = 28.35 grams.
1 ounce (Troy) = 31.1 grams.

Note. The abbreviation "lb.," for pound, comes from the Latin *libra*, scales. Our "ounce" is probably from *unus*, one, and was originally applied to $\frac{1}{12}$ of a pound, as it still is in "Troy" weight. In the form *inch* it is also used for $\frac{1}{12}$ of a foot. The ton probably received its name from the "tun," a large cask that held about 2,000 lbs. of water.

TABLE III. DENSITIES OF SOME SUBSTANCES.

Acetic acid*	1.053	Magnesium	1.75
Alcohol (ethyl)*	0.794	Marble	2.7
Aluminum	2.67	Mercury (at 0°C.)	13.596
Brass	8.3	Milk	1.032
Carbolic acid	0.95	Nickel	8.57
Carbon (charcoal)	1.6	Nitric acid (conc.)*	1.42
Carbon (gas)	1.8	Oil (cottonseed)	0.926
Carbon disulphide*	1.27	Oil (linseed)	0.942
Chloroform*	1.5	Oil (olive)	0.918
Clay	1.9	Oil (turpentine)	0.873
Coal (anthracite)	1.26 to 1.8	Paraffin	0.90
Coal (soft)	1.2 to 1.5	Phosphorus (yellow)	1.83
Copper	8.9	Platinum	21.5
Cork	0.24	Sand (dry)	1.4
Diamond	3.53	Silver	10.57
Ether*	0.72	Sodium	0.97
Gasoline	0.67	Sulphur	2.03
Glass	2.6 to 3.6	Sulphuric acid (conc.)	1.854
Glycerine	1.27	Tin	7.29
Gold	19.3	Water at 0°C.	0.999
Hydrochloric acid		Water at 4°C.	1.000
(conc.)*	1.22	Water at 100°C.	0.958
Ice	0.918	Water (sea)	1.026
Iodine	4.95	Wood (hickory, dry)	1.00
Iron	7.8	Wood (maple, dry)	0.64
Kerosene	0.79	Wood (white oak, dry)	0.86
Lead	11.35	Wood (white pine, dry)	0.42
Limestone	3.2	Zinc	6.9 to 7.2

*At 15° C.

TABLE IV. THE BEAUFORT SCALE.

FORCE	DESIGNATION	MILES PER HOUR
0	Calm	From 0 to 3
1	Light air	Over 3 to 8
2	Light breeze (or wind)	Over 8 to 13
3	Gentle breeze (or wind)	Over 13 to 18
4	Moderate breeze (or wind)	Over 18 to 23
5	Fresh breeze (or wind)	Over 23 to 28
6	Strong breeze (or wind)	Over 28 to 34
7	Moderate gale	Over 34 to 40
8	Fresh gale	Over 40 to 48
9	Strong gale	Over 48 to 56
10	Whole gale	Over 56 to 65
11	Storm	Over 65 to 75
12	Hurricane	Over 75

TABLE V. MELTING POINTS OF SOME SOLIDS.

Hydrogen	−256.5°C.	Lead	327°
Alcohol (ethyl)	−130°	Zinc	419°
Mercury	− 39.5°	Aluminum	657°
Ice	0°	Salt	820°
Olive oil	3°	Silver	961°
Acetic acid	17°	Copper	1065°
Carbolic acid	43°	Gold	1071°
Paraffin	55°	Cast iron	1200°
Sodium	97.6°	Steel (about)	1475°
Sulphur	114°	Wrought iron	1550°
Sugar (cane)	160°	Platinum	1775°
Tin	232°		

TABLE VI. BOILING POINTS OF SOME SUBSTANCES.

Hydrogen	−252°C.	Alcohol, ethyl. . .	78°
Liquid air	−190°	Water	100°
Acetylene	− 72°	Salt brine (saturated)	109°
Ammonia	− 33°	Turpentine . . .	159°
Sulphur dioxide . .	− 8°	Carbolic acid. . .	183°
Ether	35°	Camphor	205°
Chloroform . . .	61°	Glycerine	291°
Gasoline	70° to 90°	Kerosene	150° to 250°

TABLE VII. SPECIFIC HEATS.

Aluminum. . . .	0.214	Lead	0.0315
Asbestos	0.195	Magnesium . . .	0.250
Brass	0.089	Marble	0.21
Cadmium . . .	0.0567	Mercury (solid) . .	0.0319
Cement	0.20	Paraffin	0.6939
Charcoal	0.16	Platinum	0.0324
Copper	0.0952	Quartz	0.188
Diamond	0.459	Salt	0.219
Glass	0.1988	Silver	0.057
Gold	0.0324	Sugar	0.274
Granite	0.192	Sulphur	0.178
Ice	0.55	Tin	0.0562
Iron	0.114	Zinc	0.0955

TABLE VIII. VAPOR PRESSURES OF ICE AND WATER AT DIFFERENT TEMPERATURES.

Temperature	Pressure in Millimeters of Mercury	Temperature	Pressure in Millimeters of Mercury
−10°C.	2.0	29°C.	29.8
− 5°	3.0	30°	31.6
0°	4.6	31°	33.4
10°	9.2	32°	35.4
11°	9.8	33°	37.4
12°	10.5	40°	55.0
13°	11.2	50°	92.2
14°	11.9	60°	149.2
15°	12.7	70°	233.8
16°	13.6	80°	355.5
17°	14.5	90°	526.0
18°	15.4	99°	733.2
19°	16.4	99.5°	746.5
20°	17.4	100.0°	760.0
21°	18.5	111.7°	1,140
22°	19.7	120.6°	1,520
23°	20.9	133.9°	2,280
24°	22.2	159.2°	4,560
25°	23.5	180.3°	7,600
26°	25.0	201.9°	12,160
27°	26.5	213.0°	15,200
28°	28.1	224.7°	19,000

TABLE IX. MILLIGRAMS OF WATER VAPOR TO SATURATE 1 LITER OF AIR.

Temperature	Wt. of Water	Temperature	Wt. of Water	Temperature	Wt. of Water
−10°C.	2.16	4°C.	6.33	18	15.22
− 9	2.35	5	6.76	19	16.14
− 8	2.55	6	7.22	20	17.12
− 7	2.77	7	7.70	21	18.14
− 6	3.01	8	8.21	22	19.22
− 5	3.26	9	8.76	23	20.35
− 4	3.53	10	9.33	24	21.54
− 3	3.83	11	9.93	25	22.80
− 2	4.14	12	10.57	26	24.11
− 1	4.48	13	11.25	27	25.49
0	4.85	14	11.96	28	26.93
1	5.19	15	12.71	29	28.45
2	5.56	16	13.50	30	30.04
3	5.95	17	14.34	31	31.70

TABLE X. THE ELEMENTS AND THEIR SYMBOLS.

Aluminum	Al	Molybdenum	Mo
Antimony	Sb	Neodymium	Nd
Argon	A	Neon	Ne
Arsenic	As	Nickel	Ni
Barium	Ba	Niton	Nt
Bismuth	Bi	Nitrogen	N
Boron	B	Osmium	Os
Bromine	Br	Oxygen	O
Cadmium	Cd	Palladium	Pd
Cæsium	Cs	Phosphorus	P
Calcium	Ca	Platinum	Pt
Carbon	C	Potassium	K
Cerium	Ce	Praseodymium	Pr
Chlorine	Cl	Radium	Ra
Chromium	Cr	Rhodium	Rh
Cobalt	Co	Rubidium	Rb
Columbium	Cb	Ruthenium	Ru
Copper	Cu	Samarium	Sm
Dysprosium	Dy	Scandium	Sc
Erbium	Er	Selenium	Se
Europium	Eu	Silicon	Si
Fluorine	F	Silver	Ag
Gadolinium	Gd	Sodium	Na
Gallium	Ga	Strontium	Sr
Germanium	Ge	Sulphur	S
Glucinum	Gl	Tantalum	Ta
Gold	Au	Tellurium	Te
Helium	He	Terbium	Tr
Hydrogen	H	Thallium	Tl
Indium	In	Thorium	Th
Iodine	I	Thulium	Tm
Iridium	Ir	Tin	Sn
Iron	Fe	Titanium	Ti
Krypton	Kr	Tungsten	W
Lanthanum	La	Uranium	Ur
Lead	Pb	Vanadium	V
Lithium	Li	Xenon	Xe
Lutecium	Lu	Ytterbium	Yb
Magnesium	Mg	Yttrium	Y
Manganese	Mn	Zinc	Zn
Mercury	Hg	Zirconium	Zr

TABLE XI. HARDNESS OF SUBSTANCES.

We can compare the **hardness** of two bodies by **rubbing** them together; the one having the greater hardness scratches or indents the other. In the **scale of hardness** bodies usually have positions between **1** and **10.** The diamond is the only substance of hardness **10.** Substances that can be indented by the finger nail have a hardness of less than **1.** A substance of hardness **6.5** is scratched by a substance of hardness **7,** but scratches a substance of hardness **6.** The list below is taken from the Smithsonian Tables, as they are given in the *Handbook of Chemistry and Physics,* published by the Chemical Rubber Company, Cleveland, Ohio.

Substance	Hardness	Substance	Hardness
Talc	1	Flint	7
Rock salt	2	Galena	2.5
Calcite	3	Garnet	7
Fluorite	4	Glass	4.5 to 6.5
Apatite	5	Gold	2.5 to 3
Feldspar	6	Graphite	0.5 to 1
Quartz	7	Gypsum	1.6 to 2
Topaz	8	Hematite	6
Corundum	9	Hornblende	5.5
Diamond	10	Iron	4 to 5
		Kaolin	1
Agate	7	Lead	1.5
Alabaster	1.7	Magnetite	6
Alum	2 to 2.5	Marble	3 to 4
Aluminum	2	Mica	2.8
Amber	2 to 2.5	Opal	4 to 6
Anthracite	2.2	Orthoclase	6
Antimony	3.3	Platinum	4.3
Asbestos	5	Pyrite	6.3
Asphalt	1 to 2	Silver	2.5 to 3
Barite	3.3	Steel	5 to 8.5
Bell metal	4	Stibnite	2
Beryl	7.8	Sulphur	1.5 to 2.5
Bismuth	2.5	Tin	1.5
Brass	3 to 4	Tourmaline	7.3
Copper	2.5 to 3	Wax (0°C.)	0.2
Dolomite	3.5 to 4	Zinc	2.5

TABLE XII. PERCENTAGE COMPOSITION OF FOOD MATERIALS.

Food	Water	Protein	Fat	Carbohydrates	Minerals	Value of 1 lb. in Large Calories
Apples	83.2	0.2	0.4	15.9	0.3	315
Beans (dry)	12.6	23.1	2.0	59.2	3.1	1,615
Beef (round)	68.2	20.5	10.1	....	1.2	805
Beef (sirloin)	60.0	18.5	20.5	....	1.0	1,200
Bread	35.3	9.2	1.3	53.1	1.1	1,215
Butter	10.5	1.0	85.0	0.5	3.0	3,410
Candy	3.0	....	....	96.5	0.5	1,785
Cheese	30.2	28.3	35.5	1.8	4.2	2,070
Chicken	72.2	24.4	2.0	....	1.4	540
Cornmeal	15.0	9.2	3.8	70.6	1.4	1,645
Eggs	73.8	14.9	10.5	....	0.8	721
Fish (salmon)	63.6	21.6	13.4	....	1.4	965
Milk	87.0	3.6	4.0	4.7	0.7	325
Mutton (leg)	61.8	18.3	19.0	....	0.9	1,140
Oatmeal	7.6	15.1	7.1	68.2	2.0	1,850
Oysters	87.1	6.0	1.2	3.7	2.0	230
Peanuts	9.2	25.8	38.6	24.4	2.0	2,560
Pork (fresh)	52.0	16.9	30.1	....	1.0	1,600
Potatoes (white)	78.3	2.2	0.1	18.4	1.0	385
Potatoes (sweet)	69.0	1.3	0.6	28.3	0.8	480
Rice	12.0	8.0	2.0	77.0	1.0	1,700
Strawberries	90.4	1.0	0.6	7.4	0.6	180
Sugar	....	....	....	100.0	....	1,850
Tomatoes	95.3	0.8	0.4	3.2	0.3	80
Walnuts (English)	2.8	16.7	64.4	14.8	1.3	3,305

TABLE XIII. SOME 100-CALORIE PORTIONS OF FOODS AS WE EAT THEM.

	100-Calorie Portion		Distribution of Calories		
	Measure	Wt., oz.	Protein	Fat	Carbohydrate
Whole milk	⅝ cup	5.1	19	52	29
Thin cream	¼ cup	1.8	5	86	9
Cheese, full cream	2 in. × 1 in. × ⅜ in.	.9	25	72	3
Butter	1 tablespoon	.5	1	99	. .
White bread	2 slices 3 in. × 3½ × ½ in.	1.3	14	6	80
Graham bread	3 slices ⅜ in. × 2 × 3¼ in.	1.4	14	6	80
Soda crackers	4 crackers	.9	10	20	70
Gingerbread	2 in. × 2 × 1 in.	1.2	8	22	70
Plain cookies	2 cookies 2¼ in.	0.9	6	33	61
Corn flakes	1¼ cups	1.0	6	4	90
Oatmeal, cooked	1 cup	7.9	17	16	67
Farina, cooked	¾ cup	6.0	12	4	84
Macaroni, cheese	½ cup	2.1	17	39	44
Boiled custard	⅓ cup, scant	2.2	13	44	43
Ice cream	¼ cup	2.0	6	55	39
Apple pie	Sector 1½ in. wide, end	1.6	3	41	56
Egg	1⅓ egg	2.7	36	64	. .
Hamburg steak	Cake 2½ in. × ⅞ in.	2.0	55	45	. .
Roast lamb	Slice 3½ in. × 4½ × ⅛ in.	1.8	41	59	. .
Halibut steak	3 in. × 2¼ × 1 in.	3.00	61	39	. .
Bacon	4 to 5 small slices	0.5	13	87	. .
Peanuts	20 to 24 single nuts	.6	19	63	18
Tomato, canned	¾ cup	.7	12	12	76
Corn, canned	⅓ cup	3.4	16	41	43
Peas, canned	¾ cup, drained	4.4	26	3	71
Spinach, boiled	2½ cups	21.0	12	8	80
Potato, baked	1 medium	3.0	11	1	88
Cream tomato soup	⅜ cup	3.2	11	63	26
Cabbage, shredded	5 cups	11.2	20	9	71
Apple	1 large	7.5	3	5	92
Orange	1 large	9.5	7	2	91
Banana	1 large	5.5	5	6	89
Sugar	2 tablespoons	0.9	. .	. .	100
Choc. fudge	1½ in. × ¾ × 1 in.	0.9	2	20	78

From *Feeding the Family*, by Mary Swartz Rose, used by permission of The Macmillan Co., publishers.

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GLOSSARY

abdomen	(ăb-dō′mĕn)
acetic	(ȧ-sēt′ĭk)
acetylene	(ȧ-sĕt′ĭ-lēn)
adenoid	(ăd′ē-noid)
aerial	(ā-ēr′ĭ-ăl)
aeroplane	(ā′ĕr-ō-plān)
albumin	(ăl-bū′mĭn)
aldebaran	(ăl-dĕb′ă-răn)
aldehyde	(ăl′dē-hīd)
alga	(ăl′gȧ)
alluvial	(ăl-lū′vĭ-ăl)
ameba	(ȧ-mē′bă)
amorphous	(ă-môr′fŭs)
amylopsin	(ăm′ĭl-ŏp′sĭn)
Andromeda	(ăn-drŏm′ē-dă)
anemia	(ȧ-nē′mĭ-ă)
aneroid	(ăn′ĕr-oid)
aniline	(ăn′ĭ-lĭn)
anopheles	(ă-nŏf′ē lēs)
anthracite	(ăn′thrȧ-sīt)
antitoxin	(ăn′tĭ-tŏx′ĭn)
appendicitis	(ă-pĕn′dī-sī′tĭs)
aorta	(ā-ôr′tă)
aqueduct	(ăk′wē-dŭkt)
aqueous	(āk′wē-ŭs)
armature	(är′mä-tiur)
Assouan	(äs′oo-än′)
astigmatism	(ā-stĭg′măt-ĭsm)
Auriga	(ä-rī′gä)
avoirdupois	(ăv′ĕr-dŭ-poiz′)
axillary	(ăx′ĭl-ā′rĭ)
bacilli	(bȧ-sĭl′ī)
bacteria	(băk-tē′rĭ-ă)
barometer	(bȧ-rŏm′ē-tĕr)
basalt	(bäs′awlt)
Betelgeuze	(bē′tl-gūz)
biceps	(bī′sĕps)
bicuspids	(bī-kŭs′pĭds)
bronchi	(brŏn′kī)
buoyant	(boi′ănt)
cactus	(kăk′tŭs)
caisson	(kā′sŏn)
calcium	(kăl′sĭ-ŭm)
calorie	(kăl′ō-rĭ)
calorimeter	(kăl′ō-rĭm′ē-tĕr)
calyx	(kā′lĭx)
canine	(kā′nīn)
Capella	(kȧ-pĕl′a)
capillary	(kăp′ĭl-ā′rĭ)
carbohydrate	(kär′bō-hī′drāt)
carburetor	(kär′bū-rĕt′ĕr)
carnivorous	(kär-nĭv′ō-rŭs)
cartilage	(kär′tĭ-lāj)
casein	(kā′sē-ĭn)
Cassiopeia	(kăs′ĭ-ō-pē′yä)
cellulose	(sĕl′ū-lōs)
centigrade	(sĕn′tĭ-grād)
centimeter	(sĕn′tĭ-mē′tĕr)
centrifugal	(sĕn-trĭf′ū-găl)
ceramics	(sē-rām′iks)
cereal	(sēr′ē-ăl)
cerebellum	(sĕr′ē-bĕl′ŭm)
cerebrum	(sĕr′ē-brŭm)
chassis	(chăs′ĭs)
chloride	(klō′rĭd)
chlorine	(klō′rĭn)
chlorophyll	(klō′rō-fĭl)
choroid	(kō′roid)
chrysalis	(krĭs′ă-lĭs)
chyle	(kīl)
chyme	(kīm)
cilia	(sil′ĭ-ä)
circuit	(sûr′kĭt)
cirrus	(sĭr′ŭs)
clavicle	(klăv′ĭ-kl)
coagulate	(kō-ăg′ū-lāt)
coccyx	(kŏk′sĭks)
cochlea	(kŏk′lē-ä)
cocoon	(kō-ko͞on′)
commutator	(kŏm′ū-tā′tĕr)
composite	(kŏm-pŏs′ĭt)
conduit	(kŏn′dĭt)
conglomerate	(kŏn-glŏm′ē-rāt)
conifer	(kō′nĭ-fĕr)

conjunctiva	(kŏn′jŭnk-tī′vă)
contagious	(kŏn-tāj′ŭs)
cornea	(kawr′nē-ä)
corolla	(kō-rŏl′ä)
corpuscle	(kawr′pus′l)
cotyledon	(kŏt′ĭl-ē′dŏn)
crystalline	(krĭs′tăl-ĭn)
cumulus	(kū′mū-lŭs)
Cygnus	(sĭg′nŭs)
deciduous	(dē-sĭd′ū-ŭs)
decimeter	(dĕs′ĭ-mē′tĕr)
declination	(dĕk′lĭ-nā′shŭn)
dentine	(dĕn′tĭn)
Dewar	(diū′ȧr)
diaphragm	(dī′ȧ-frăm)
dichromate	(dī-krōm′āt)
dielectric	(dī′ē-lĕk′trĭk)
dietetics	(dī′ē-tĕt′ĭks)
diphtheria	(dĭf-thē′rĭ-ȧ)
dirigible	(dĭr′ĭ-jĭb′l)
dynamo	(dī′nȧ-mō)
effervesce	(ĕf-ĕr-vĕs′)
electrolysis	(ē′lĕk-trŏl′ĭ-sĭs)
embryo	(ĕm′brĭ-ō)
endosperm	(ĕn′dō-spĕrm)
environment	(ĕn-vīr′ŏn-mĕnt)
enzyme	(ĕn′zīm)
epidemic	(ĕp′ĭ-dĕm′ĭk)
epidermis	(ĕp′ĭ-dĕr′mĭs)
epiglottis	(ĕp′ĭ-glŏt′ĭs)
epithelial	(ĕp′ĭ-thē′lĭ-ăl)
esophagus	(ē-sŏf′ȧ-gŭs)
Fahrenheit	(fä′rĕn-hīt)
fibrinogen	(fī-brĭn′ō-gĕn)
focus	(fō′kŭs)
formaldehyde	(fôrm-ăl′dē-hīd)
galaxy	(găl′ăx-ĭ)
Galileo	(găl′ĭ-lē′ō)
Galvani	(gäl′vä′nē)
ganglia	(găn′glĭ-ȧ)
germicide	(jĕrm′ĭ-sīd)
glycogen	(glī′cō-jĕn)
Greenwich	(grĭn′ĭj)
Guernsey	(gŭrn′zĭ)
hemoglobin	(hē′mō-glō′bin
hepatica	(hē-păt′ĭ-kȧ)
herbivorous	(hĕr-bĭv′ō-rus)
hibernate	(hī′bĕr-nāt)
humerus	(hū′mĕr-ŭs)
hydrometer	(hī-drŏm′ē-tĕr)
hydroxide	(hī-drŏx′ĭd)
hygiene	(hī′jĭ-ēn)
hypocotyl	(hī′pō-kot′l)
ignition	(ĭg-nĭ′shŭn)
imago	(ī-mā′gō)
incandescent	(ĭn′kăn-dĕs′ĕnt)
incisor	(ĭn-sī′zēr)
incubation	(ĭn′kū-bā′shŭn)
inertia	(ĭn-ĕr′shi-ȧ)
inoculation	(ĭn-ŏk′ū-lā′shŭn)
insulator	(ĭn′sū-lā′tĕr)
intestine	(ĭn-tĕs′tĭn)
isolation	(ī′sō-lā′shŭn)
kilometer	(kĭl′ō-mē′tĕr)
Krakatoa	(krăk′ȧ-tō′ȧ)
lachrymal	(lăk′rĭ-măl)
lacteal	(lăk′tē-ăl)
la grippe	(lä grĭp′)
larvae	(lär′vē)
Lavoisier	(lȧ′vwȧ′zyā)
legume	(lĕg′yūm)
Leverrier	(lĕ′vĕr′yā′)
Leyden	(lī′dĕn)
lichen	(lī′kĕn)
lymphatic	(lĭm-făt′ĭk)
magneto	(măg-nē′tō)
manganese	(măn′găn-ēs)
medulla oblongata	(mē-dŭl′ȧ ŏb′lŏn-gä′tȧ
meniscus	(mē-nĭs′kŭs)
metamorphic	(mĕt′ȧ-môr′fĭc)
metatarsal	(mĕt′ȧ-tär′săl)
meteorology	(mē′tē-ôr-ŏl′ōgĭ)
microbe	(mī′krōb)
micrococcus	(mī′krō-kŏk′ŭs)
Mizar	(mī′zär)
molecule	(mōl′ē-kiūl)
momentum	(mō-mĕn′tŭm)
monocotyl	(mō′nō-kot′ĭl)
monoxide	(mōn-ŏx′ĭd)
mucous	(mū′kŭs)
muriatic	(mū′rĭ-ăt′ĭk)
nitrifying	(nī′trĭ-fī′ĭng)
nitrogenous	(nī-trŏj′ē-nŭs)
nucleus	(nū′klē-ŭs)
olfactory	(ŏl-făk′tō-rĭ)
omnivorous	(ŏm-nĭv′ō-rŭs)
Orion	(ō-rī′ŏn)
oxalic	(ŏx-ăl′ik)
oxyhemoglobin	(ŏx′ĭ-hē′mō-glō′bĭn)

palate	(păl′āt)
pancreas	(păn′krē-ăs)
pancreatic	(păn′krē-ăt′ĭk)
papilla	(pȧ-pĭl′a)
Pasteur	(pȧs-tûr′)
patella	(pȧ-tĕl′ȧ)
penumbra	(pē-nŭm′brȧ)
perennial	(pĕr-ĕn′ĭ-ăl)
pericardium	(pĕr′ĭ-kȧrd′ĭ-ŭm)
peripheral	(pĕr-ĭf′ĕr-ăl)
periosteum	(pĕr′ĭ-ŏs′tē-ŭm)
petiole	(pĕt′ĭ-ōl)
phalanges	(fȧ-lăn′jēz)
pharynx	(făr′ĭnks)
phenomena	(fē-nŏm′ē-nȧ)
phosphorus	(fŏs′fōr-ŭs)
photometer	(fō-tōm′ē-tĕr)
photosynthesis	(fō′tō-sĭn′thē-sĭs)
pistillate	(pĭs′tĭ-lāt)
Pleiades	(plē′jȧ-dēs)
pleurae	(plū′rē)
pleurococcus	(plū′rō kŏk′ŭs)
plumule	(plū′miūl)
pneumatic	(nū-măt′ĭk)
Polaris	(pō-lā′rĭs)
posterior	(pŏs-tē′rĭ-ĕr)
potassium	(pō-tăs′ĭ-ŭm)
proboscis	(prō-bŏs′ĭs)
protein	(prō′tē-ĭn)
protoplasm	(prō′tō-plăzm)
protozoa	(prō′tō-zō′ȧ)
ptomaine	(tō′mȧ-ĭn)
ptyalin	(tī′ȧ-lĭn)
pulmonary	(pŭl′mō-nā′rĭ)
pulmotor	(pŭl′mō-tôr)
puparium	(piū-pā′rĭ-ŭm)
pylorus	(pī-lō′rŭs)
pyrogallic	(pī′rō-găl′ĭk)
pyrometer	(pī-rŏm′ē-tĕr)
quarantine	(kwôr′ăn-tēn)
retina	(rĕt′ĭ-nȧ)
retort	(rē-tôrt′)
rheostat	(rhē′ō-stăt)
Rigel	(rē′gĕl)
sal ammoniac	(săl ăm-ōn′ĭ-ak)
salicylic	(săl′ĭ-sĭl′ĭk)
salivary	(săl′ĭ-vā′rĭ)
saprophyte	(săp′rō-fīt)
sclerotic	(sklēr-ŏt′ĭk)
scorbutic	(skŏr-bū′tĭk)

sebaceous	(sē-bā′shŭs)
secrete	(sē-krēt′)
sedentary	(sĕd′ĕn-tā′rĭ)
sepal	(sē′păl)
sidereal	(sī-dē′rē-ăl)
silica	(sĭl′ĭ-kȧ)
siphon	(sī′fŏn)
Sirius	(sĭ′rĭ-ŭs)
somatic	(sō-măt′ĭk)
species	(spē′shēz)
spectrum	(spĕk′trŭm)
spinach	(spĭn′ĭj)
sputum	(spiū′tŭm)
staminate	(stăm′ĭ-nāt)
steapsin	(stē-ăp′sĭn)
stegomyia	(stēg-ō′mĭ-yă)
stipule	(stĭp′ūl)
stomata	(stō′mä-tȧ)
stratus	(strā′tŭs)
strychnine	(strĭk′nĭn)
sublimate	(sŭb′lĭ-māt)
sulphide	(sŭl′fĭd)
tangent	(tăn′jĕnt)
thermometer	(thĕr-mŏm′ē-tĕr)
thyroid	(thī′roid)
Torricelli	(tôr′ĭ-chĕl′lē)
tourniquet	(tŭr′nĭ-kĕt)
trachea	(trāk′ē-ȧ)
trichinae	(trĭ-kīn′ē)
trypsin	(trĭp′sĭn)
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turbine	(tŭr′bĭn)
tympanum	(tĭm′păn ŭm)
Uranus	(yŭ′rā nŭs)
Ursa major	(ûr′sȧ māj′ĕr)
vaccination	(văk′sĭ-nā′shŭn)
vacuum	(văk′ū-ŭm)
vertebra	(vĕr′tē-brȧ)
villi	(vĭl′ī)
visceral	(vĭs′ĕr-ăl)
vitamin	(vīt′ă-mĭn)
vitreous	(vĭt′rē-ŭs)
vitriol	(vĭt′rĭ-ŏl)
Volta	(vôl′tä)
whorl	(hwûrl)
xylophone	(zī′lō-fōn)
zenith	(zē′nĭth)
zodiac	(zō′dĭ-ăk)
zymase	(zī′mās)

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